The WELDING JOURNAL

DECEMBER 1953

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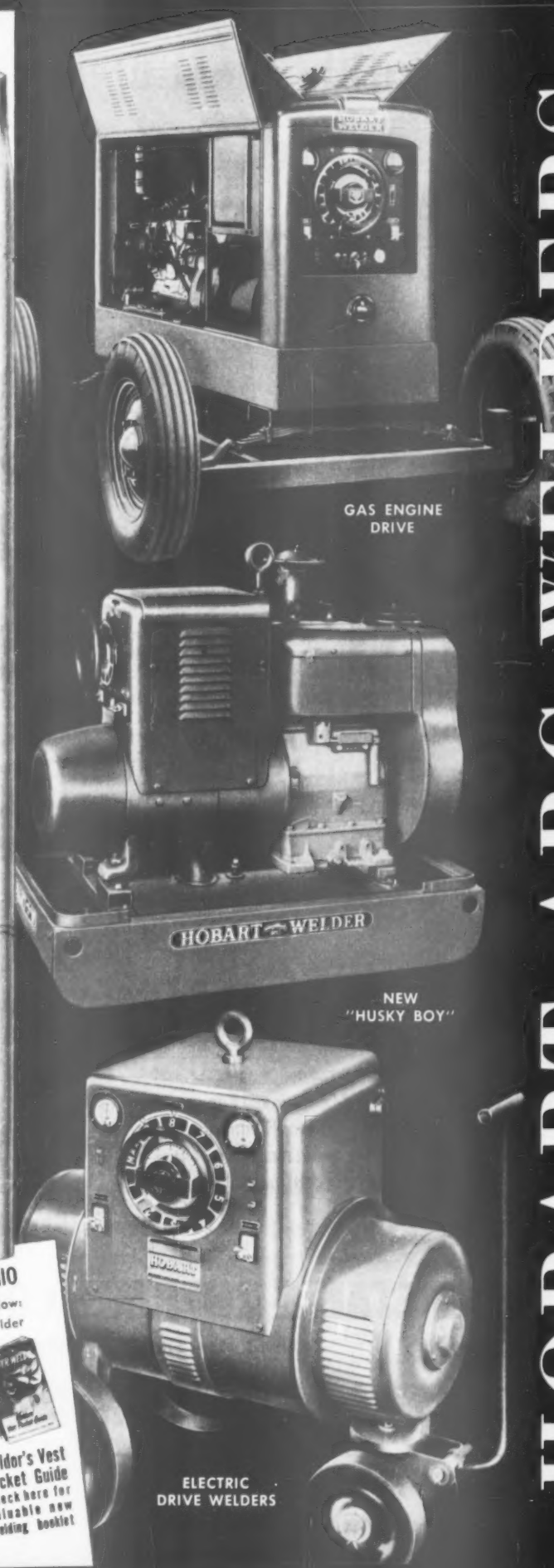

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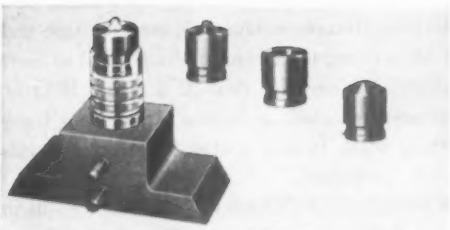

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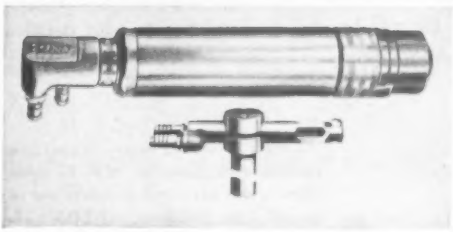

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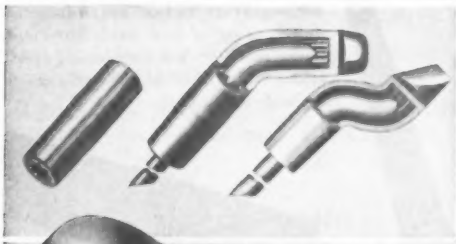

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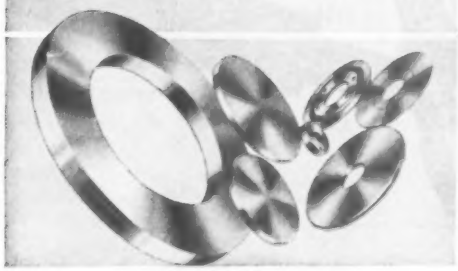

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The WELDING JOURNAL

volume 32 December 1953 number 12

Weldability of Structural Steel

The subject of weldability of structural steel is discussed from the point of view of the Federal agencies

by E. L. Erickson

INTRODUCTION

ENGINEERS of the Federal agencies are as much concerned with the proposition of obtaining for use in welded structures a steel that can be safely welded as is private industry. We have been only too forcefully reminded through the experiences of the shipbuilding program of World War II and the research which followed, that although it may be possible to weld almost any steel, the effects of welding on some steels can be disasterous in so far as the safety of a structure is concerned.

This fact has been recognized for some time. Our literature on the subject of welding has consistently tied the weldability of steel with its chemical composition. Carbon content has generally been taken as a principal measure of weldability, often in combination with manganese, silicon and other elements. The limiting amount of carbon set by most authorities for a steel suitable for welding has been 0.25%.

In recognition of these facts, government engineers concerned with structural welding have advocated and produced, with the aid of the steel industry, Federal Specifications for steels considered suitable for welding. These include Federal Specification QQ-S-741, Steel, Structural, for Bridges and Buildings, promulgated Dec. 9, 1942, and military specifications covering steels of welding quality for ships and for military bridges. These steels all come under the head of "Quality Material," therefore extras are high and they are not always commercially available. Consequently, they are not the final answer to the problem of obtaining a weldable steel for general use. In spite of the vast amount of research done by such groups as the Ship Committee, Battelle Institute of Industrial Research, The American Iron and Steel Institute and others, we who express concern about the integrity of welded structures when little or no attention is paid to the suitability of material are often told that there is no need for concern, and to specify a welding quality steel is a needless expense in view of the past record of our commercial structural steel, ASTM-A7. While it is true that the failure of welded structures has been infrequent in this country, we do not know how much we have infringed on our factors of safety nor how close to failure many standing structures are. Must we suffer a major catastrophe in the case of a welded bridge or other structure with possible accompanying loss of life before we are willing to recognize the necessity of using a proper material?

REQUIREMENTS FOR A STEEL SUITABLE FOR WELDED STRUCTURES

Weldability may be defined as the ease with which a material can be welded with due consideration to all variables and to the necessity of obtaining acceptable physical properties.

The physical characteristics of the ASTM-A7 steel, which has been the material most generally used for buildings and bridges, are considered about the minimum economic requirements for structural work. The principal properties are shown in Table 1. Except for sulfur and phosphorus the chemical properties are not specified. It is for this reason coupled with the fact that the carbon content actually goes up to about 0.35%, that A7 steel should not be considered to be of a suitable weldability for safe use in structures having their principal connections made by welding. Although much of the A7 steel being manufactured at the present time has a chemistry providing good weldability, the fact that there are under the present specifica-

E. L. Erickson is Chief, Bridge Branch, Bureau of Public Roads, Department of Commerce, Washington 25, D. C.

Presented at the AWS National Fall Meeting held in Cleveland, Ohio, the week of Oct. 19, 1953.

tions no restrictions on those elements which affect the weldability has motivated an effort to obtain a specification acceptable to the steel industry having the physical properties of A7 steel and a chemistry sufficiently restrictive to assure a satisfactory weldability.

Table 1

Chemical requirements

	Ladle analysis	*Check analysis*
Phosphorus, max, %:		
Open-hearth or electric-furnace:		
Acid	0.06	0.075
Basic	0.04	0.05
Acid—Bessemer	0.11	0.138
Sulfur, max, % (open-hearth or electric-furnace)	0.05	0.063
Copper, when copper steel is specified, min, %	0.20	0.18

Tensile requirements

	Plates, shapes and bars
Tensile strength, psi	60,000 to 72,000*
Yield point, min, psi	33,000
Elongation in 8 in., min, %	21
Elongation in 2 in., min, %	24

* The upper limit of 72,000 psi may be increased by 3000 psi for material over 1½ in. in thickness.

The Federal Government is interested in the construction of a large variety of steel structures on which welding can be used to economic advantage, including bridges, buildings, towers, docks, hydroelectric structures, navigation structures, etc. When welding is applied to such structures sufficient public interest and public safety is involved to demand that those responsible furnish a safe and efficient structure.

Following World War II, the Ship Structure Committee was organized for the purpose of studying welded ship design and construction. These studies have brought to light many fundamental facts concerning the weldability of structural steels. Included in the findings to date are these interesting facts:

(1) Generally notch sensitivity increased as plate thickness increased.

(2) For a particular strength level, steels with higher manganese to carbon ratios have lower transition temperatures.

(3) The manganese carbon ratio may be a factor contributing to notch sensitivity.

(4) The tear test transition temperature was raised appreciably by increases in carbon, phosphorus and vanadium content.

(5) Increases in carbon and manganese content, especially carbon, were accompanied by marked increase in crack sensitivity.

(6) In plates of equal thickness (and hence equal metallurgically) transition temperature rises with the width.

(7) Transition temperature in rolled steels gradually decreases as the extent of deoxidation increases.

The weldability of structural steel decreases rapidly as the carbon content exceeds the range from 0.20 to 0.25% but the relationship is a complex one and beyond the scope of this discussion. Some of the procedures which tend to improve weldability are increased heat input, preheat, postheat and selection of electrode.

DEVELOPMENT OF A STEEL SUITABLE FOR WELDED BRIDGES AND BUILDINGS

Under this part of the discussion we shall consider recent steps which have been taken to obtain acceptance of a specification for a weldable steel of a commercial quality by industry and consumer.

In so far as bridges and buildings are concerned ASTM-A7 steel has been used almost entirely. The savings possible in material and over-all cost by the use of welding have brought about a change in thinking on the part of bridge engineers, other structural engineers and the steel fabricating industry so that much work previously riveted or bolted is now being welded. Although Federal Specification steels of welding quality could be obtained, the mill extras have been high. Also, deliveries have been uncertain in these days of structural steel shortages, thus rendering such steels unattractive, especially for small jobs.

Numerous attempts were made by both industry and consumer members of the AMERICAN WELDING SOCIETY Bridge Committee to obtain agreement on a specification for a weldable steel. Little progress was made, however, until August of 1951 when at the request of F. W. Panhorst, Bridge Engineer of the California State Highway Department, the author called a conference in Washington attended by Jonathan Jones, Chief Engineer, and Paul Gerhart, Chief Metallurgist, Bethlehem Steel Co.; Earl Davidson, Metallurgical Engineer of the U. S. Steel Corp.; and Raymond Archibald, Nathan Morgan and the author representing the Bureau of Public Roads.

The purpose of this meeting was to obtain agreement with the steel industry for a welding quality steel to be used in the construction of the Bay Shore Freeway elevated highway structures in San Francisco (a Federal-aid project), which job is the largest all-welded bridge job so far attempted in the world involving some 26,000 tons of steel. Prior to this meeting various attempts had been made to set up a suitable specification, but nothing satisfactory from an engineering viewpoint had been produced.

At this Washington meeting the steel company representatives advised that their companies would agree to furnish "for this project," the Bay Shore Freeway in San Francisco, a steel having the characteristics shown in Table 2; the carbon content to be 0.25% for plates ½ in. and over; plates over 1 in. would be silicon killed; manganese content was specified for plates over ½ in.; tensile strength was 58,000 to 75,000 and yield 32,000 for all thicknesses.

Concerning shapes the metallurgists of both steel companies stated that they could not apply the plate specification to shapes and suggested that existing shape

Table 2

Chemical requirements (plates only)

	Ladle analysis		
	To 1/2 in.	*Over 1/2 in., to 1 in., incl.*	*Over 1 in. thickness*
Carbon max, %	....	0.25	0.25
Manganese, %	....	0.50–0.90	1.15 max
Phosphorus max, %	0.04	0.04	0.04
Sulfur max, %	0.05	0.05	0.05
Silicon, %	....	....	0.15–0.30

Physical requirements (plates only)

	Thickness		
	To 1/2 in.	*Over 1/2 in. to 1 in., incl.*	*Over 1 in.*
Tensile strength	58,000–75,000	58,000–75,000	58,000–75,000
Yield	32,000	32,000	32,000
Elongation in 8 in. min, %	21	21	21
Elongation in 2 in. min, %	.....	23	23

For material over 3/4 to 2 1/2 in., inclusive, in thickness, a deduction from the percentage of elongation in 8 in. specified of 0.25% shall be made for each increase of 1/32 in. of the specified thickness of 3/4 in. to a minimum of 19%.

specifications be used. They made these recommendations:

A7 Steel may be used for all shapes and plates not welded where high-tensile low-alloy steel is not necessary or desirable.

A7 Steel may be used for structural shapes up to and including 1 in. thickness, where connections are to be made by welding.

The new specification should be used for plates to be welded.

Navy 46 SIj, June 1, 1945 (currently Mil-S-20166), HT Grade for shapes over 1 in. thickness, where welding is involved.

Navy Specification Mil-S-16113 (Ships) Apr. 15, 1951, is suitable for all welded plate work and should be used where its high-tensile strength properties are economically advantageous.

NOTE: Several contracts of the Bay Shore Freeway project are now under construction. For a more detailed description, see article by L. C. Hollister in *Civil Engineering*, September 1952.

Following the last war, the Office of Defense Mobilization organized a Committee to investigate the possibility of conserving structural steel. J. W. Follin was made chairman of the Subcommittee on Construction for the Conservation Division, Defense Production Administration. His group held several meetings and attempted to prepare a new specification for a welding grade of steel for Federal building construction. This committee worked in conjunction with both the AWS and the ASTM. The committee was especially concerned with seeking to reduce the cost of welding quality steel under Federal Specification QQ-S-741.

In January of 1953 Mr. Davidson of the U. S. Steel Corp. presented a proposed revision to the August 1951 specification which covered shapes as well as plates, advising that in his opinion this represented the very best that the steel industry would be able to do at the present time with regard to a commercial grade welding quality steel for general use. The basic features of this proposed specification are as follows:

Proposed Revision of Bureau of Public Roads Specification

Covering
Steel for State of California Bridge Department
Bayshore Freeway Project

Plate material

Thickness	*Carbon, %*	*Manganese, %*	*Silicon, %*
To 1/2 in., inclusive	0.26 max		
Over 1/2 to 1 in., inclusive	0.25 max	0.50–0.90	....
Over 1 to 2 in., inclusive	0.26 max	0.50–0.90	0.15–0.30
Over 2 to 4 in., inclusive	0.27 max	0.50–0.90	0.15–0.30

Structural shapes

Thickness	*Carbon, %*	*Manganese, %*
Intermediate and light web and flange thickness	0.28 max.	
Heavy web and flange sections in all foot weights	0.28 max	0.50–0.90
CB 103 10 x 10 in.		
CB 124 12 x 12 in.		
CB 145 14 x 14 1/2 in.		
CB 146 14 x 16 in.		
CB 213 21 x 13 in.		
CB 243 24 x 14 in.		
CB 272 27 x 14 in.		
CB 301 30 x 10 1/2 in.		
CB 302 30 x 15 in.		
CB 331 33 x 11 1/2 in.		
CB 332 33 x 15 3/4 in.		
CB 361 36 x 12 in.		
CB 362 36 x 16 1/2 in.		

For all above plate and shape thickness groups:
Phosphorus 0.04 Sulfur 0.05

All above composite limits based on ladle analysis with standard check analysis limits to apply:
Tensile strength ..... 58,000 to 75,000
Yield point, min. 32,000

Elongation and Bend requirements and modification clauses of A7 apply.

For girders to be built up by welding plate material or other plate thicknesses as well as the CB sections listed above, industry high-strength low-alloy grades to ASTM A242 could be specified for use in order to eliminate or reduce to a minimum the preheating required in connection with field welding. These steels offer higher strength values than the above 58,000 tensile strength, 32,000 yield point minimum, respectively. U. S. Steel Corp. 1/14/53.

On Jan. 29, 1953, the Federal Supply Service of the General Services Administration adopted Mr. Davidson's recommendation and published Interim Federal Specification QQ-S-00741(GSA-FSS) as a proposed revision to QQ-S-741, dated Dec. 9, 1942. This new interim specification is a radical departure from the old Federal Specification in that basic requirements for manufacture and testing now conform to current American Society for Testing Materials Specification A6 and A7 which has the effect of substantially reducing mill extras. This will result in a large monetary saving to the Federal Government. This specification became immediately acceptable to the ODM group.

The Conference Committee of the Bridge Committee of the AMERICAN WELDING SOCIETY adopted this same basic specification as the AMERICAN WELDING SOCIETY Specification for Steel for Welded Bridges on May 27, 1953. Also the American Society for Testing Materials Committee A1 at their meeting at Atlantic City on July 1, 1953, recommended to the Society that it adopt this specification, and final adoption waits approval by letter ballot of the Committee and the Society as a whole.

Thus it appears that after many years of effort, we now have an acceptable specification for a welding steel. It must be realized, however, that this new steel specification is not ideal in that the carbon content is still high so that special workmanship is required to insure safe construction when working with the heavier thicknesses. Yet, whatever shortcomings this new specification may have, a great step forward has been made which broadens the horizon for the welding of steel bridges, buildings and other structures.

In a discussion such as this it would be remiss not to mention some of the other steels available to the structural engineer faced with a structural welding problem. Probably the best welding steels we have today are those in the Navy's specifications Mil-S-20166, Oct. 3, 1951, for shapes and Mil-S-16113 (ships), Apr. 15, 1951, for plates. The chemical and physical requirements for the HT Grade are shown in Table 3.

Much has been said about the cost of obtaining a controlled steel for welding and the costs of the various Federal Specification steels have been pointed to with alarm. Mill extras for the new steel, A7, and some Federal Specification steels are shown in Table 4.

Table 3

Chemical composition, shapes

Grade	HT
Carbon, max, %	0.18
Manganese, max, %	1.30
Phosphorus, max, %	0.04
Sulfur, max, %	0.05
Silicon, %	0.15–0.35
Copper, max, %	0.35
Nickel, max, %	0.25
Titanium, min, %	0.005
Vanadium, min, %	0.02
Chromium, max, %	0.15
Molybdenum, max, %	0.05

Physical properties—shapes

Thickness, in.	*Tensile strength per sq. in.*	*Yield point per sq. in., min*
Under 1/4	90,000	50,000
1/4 to 1/2 incl.	87,000	48,000
Over 1/2 to 1, incl.	84,000	45,000
Over 1 to 2, incl.	84,000	42,000
Over 2	82,000	40,000

Chemical composition, plates—Check analysis

Grade	HT
Carbon, max, %	0.18
Manganese, max, %	1.30
Phosphorus, max, %	0.040
Sulfur, max, %	0.050
Silicon, %	0.15–0.35
Copper, max, %	0.35
Nickel, max, %	0.25
Vanadium, min, %	0.02
Titanium, min, %	0.005
Chromium, max, %	0.15
Molybdenum, max, %	0.05

Mechanical properties—Plates

Grade	*Thickness, psf*	*Ultimate tensile strength, psi*	*Yield point, min, psi*
HT	Under 20.4, excl.	92,000	50,000
	20.4 to 61.2, incl.	88,000	47,000
	Over 61.2 to 81.6	86,000	44,000
	Over 81.6	85,000	42,000

Table 4—Mill Extras, Dollars per Ton, Aug. 6, 1953

			Old QQ-S-741			
Plates	*A 7*	*New Steel*	*Type I Grade A Class 1*	*Type II Grade A Class 1*	*Mil-S-20166 Grade HT*	**Mil-S-16113 Grade HT*
Up to 1/2 inch	1.00	2.00	4.00	18.00	...	51.00
Over 1/2 to 1 inch	1.00	4.00	4.00	18.00	...	71.00
Over 1 to 1 1/2 inch	1.00	14.00	4.00	18.00	...	71.00
Over 1 1/2 to 3 inch	14.00	17.00	17.00	(to 2 1/2 in.) 21.00	...	75.00
Over 3 to 4 inch	16.00	19.00	19.00	...	...	77.00
Shapes in foot weights, web and flange thickness						
Intermediate and light	...	2.00	...	18.00	47.00	...
Heavy	...	4.00	...	18.00	47.00	...

* Amounts shown include normalizing.

Now that we have agreement on a steel for welding, the next question that arises is—What are the workmanship requirements that go along with it? A study of the preheating and electrode requirements for various types of steel with different chemistries has recently been concluded by the Welding Research Council. These have recently been published in *Weldability of Steels* by R. D. Stout and W. D. Doty, published in 1953 by the Welding Research Council. The AWS Subcommittee on Workmanship Technique has adopted for inclusion in the AWS Specification for Highway and Railway bridges, the requirements shown in Table 5.

In conclusion the following is quoted from an editorial in the *Engineering News-Record*, dated July 16, 1953:

"The purpose of the new specification is to minimize the possibility of brittle failures in large welded structures, chiefly bridges. Though brittle failures have occurred in riveted or bolted structures, damage to large welded structures failing in this manner usually is more severe, because cracks can pass through welds and spread over a wide area.

"The new specification attempts to prevent brittle failures through requirements for chemical composition. These insure against low-notch toughness and segregations in the steel, eliminate "rimmed" steels altogehert and make certain that only fully-killed steel will be furnished for thick material. Because of the influence of the chemical requirements on steel-mill practices, the weldable steel probably will cost more than A7 steel.

"Some engineers may consider the additional cost of the weldable steel a needless expense in view of the satisfactory past record of A7 steel. Also, they may claim that a large portion of A7 steel now being produced could meet the new specification substantially anyway. However, the absence from A7 of requirements for elements other than phosphorus, sulfur and copper leaves the door open for the production of steel that may not be suitable for certain welded structures—and it may be noted, sometimes not even for some riveting or bolting applications.

"The question may well be raised, therefore, as to whether A7 should have been modified to extend protection to all structural steel rather than a new specification introduced. Certainly, a single specification for structural steel that would be applicable regardless of how the material is to be connected is highly desirable, and A7, already in widespread use, could well be adapted for the purpose."

Table 5—Welding Requirements

Thickness	*Preheat, interpass temperatures and electrode requirements*
Plates to 1/2 in. thick, incl.	None required
Plates over 1/2 to 1 in. thick, incl.	None required
Plates over 1 to 2 in. thick, incl.	EXX15 or EXX16 electrodes. No welding to be done below 10° F or 200° F preheat and interpass temperature
Plates over 2 to 4 in. thick, incl.	100° F min preheat and interpass temperature with EXX15 or EXX16 electrodes or 300° F min preheat and interpass temperature
Bars and shapes with intermediate and light web and flange to 1/2 in. thick, incl.	None required
Bars and shapes with intermediate and light web and flange 1/2 in. to 1 in. thick, incl.	100° F preheat and interpass temperature or EXX15 or EXX16 electrodes. No welding to be done below 10° F.
Bars and shapes with heavy web and flange	EXX15 or EXX16 electrodes. No welding to be done below 10° F or 200° F preheat and interpass temperature

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(*Continued on page 1194*)

Repair Welding of Ceramic-Coated Alloys

Laboratory tests indicate procedures for field repairs of several alloys for high-temperature aircraft application

by J. M. Riordan

INTRODUCTION

THE critically short supply of the highly alloyed materials used in fabricating the "hot" parts of aircraft engines—jet and reciprocating—has developed a demand for increased service life and, in many instances, the substitution of leaner alloys for these parts.

To achieve longer life and successful substitution of lower alloys, high-temperature ceramic coatings have been applied to such parts with satisfactory results. Among the most successful of the high-temperature ceramic coatings are those of the Solar Aircraft Co. identified by the trademark "Solaramic." These coatings are applied to a number of "hot" parts including jet engine combustion chamber liners, crossover tubes and transition sections, and reciprocating engine exhaust manifold systems, turbosupercharger nozzle boxes and turbo hoods.

However, the use of the ceramic coatings has given rise to the problem of developing proper methods of making repairs in the field on parts damaged in transportation, assembly and service. Since such repair work frequently involves fusion welding, Solar Aircraft Co. has made an extensive study of practical weld repair techniques for alloys protected with Solaramic coatings.

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Welding processes studied included inert-gas-shielded arc and oxy-acetylene gas welding of typical heat-resistant alloys and also of a material with a significantly lower alloy content. These representative materials were Solaramic coated: AISI Types 310 and 321 stainless steels, the International Nickel Co.'s Inconel, Haynes-Stellite N-155 and Timken's Sicromo 58. Although the chemical compositions of those alloys are familiar to many, a nominal analysis of these materials is provided in Table 1 for information purposes.

PREPARATION OF TEST SPECIMENS

A number of coupons of each alloy to be tested were sheared from 0.050-in. stock, the 0.050 in. thickness being representative of the thickness of a number of relevant parts which are being fabricated and ceramic coated in production lots.

Each sample was coated with an applicable Solaramic coating 0.0015 in. thick, that being the average thickness of coatings for the representative parts.

The test specimens were made by welding together two coated coupons, weldments being made with a single pass through the ceramic, and filler wire added being of the same alloy as the coupons.

Half of the specimens were made using the inert-gas-shielded arc process, in which case it was necessary to chip the ceramic to bare a small spot of base metal so the arc could be struck. The remaining specimens were obtained by the oxy-acetylene process. Results of the inert-gas-shielded arc tests are in general obtainable

Table 1—Chemical Compositions of Alloys Tested

	Alloy				
Analysis	*Type 321*	*Type 310*	*Inconel*	*N-155*	*Sicromo 58*
Carbon	0.08 max.	0.08 max.	0.15 max.	0.08–0.16	0.15 max.
Manganese	1.00–2.00	2.00 max.	1.00 max.	1.00–2.00	0.50 max.
Silicon	1.00 max.	1.00 max.	0.75 max.	1.00 max.	1.00–2.00
Phosphorus	0.040 max.	0.040 max.	.....	0.040 max.	0.040 max.
Sulfur	0.030 max.	0.030 max.	.....	0.030 max.	0.030 max.
Chromium	17.00–19.00	24.00–26.00	14.00–17.00	20.00–22.50	4.00–6.00
Nickel	8.00–11.00	19.00–22.00	72.00 min.	19.00–21.00	.....
Titanium	6XC–0.70 max.	.....	.....	.....	.....
Molybdenum	0.50 max.	0.50 max.	.....	2.50–3.50	0.45–0.65
Copper	0.50 max.	0.50 max.	0.50 max.	.....	.....
Iron	Balance	Balance	6.00–10.00	Balance	Balance
Cobalt	.....	.....	1.00 max.	18.50–21.00	.....
Tungsten	.....	.....	.....	2.00–3.00	.....
Columbium	.....	.....	.....	0.75–1.25	.....
Nitrogen	.....	.....	.....	0.10–0.20	.....

with metallic arc provided the under side of the weld area is fluxed or a suitable backing bar is used.

All specimens were subjected to an annealing heat treatment to remove localized stresses resulting from the welding operation. This was followed by air cooling.

After annealing, each specimen was partially re-welded by laying a second pass of approximately 50% penetration on the original weld, using the same weld method from the same side as the initial pass. The purpose of the second pass was to impose a stress on the lower half of the original weld, thus aggravating any discontinuities present.

TEST PROCEDURES

Defects considered most likely to result from the repair welding of ceramic-coated parts include cracks, nonfusion and inclusion of entrapped ceramic elements. Therefore, subsequent examination utilized methods best suited for detecting these types of imperfections.

First, the welds in each specimen were examined with a binocular microscope to determine the over-all quality relative to apparent external defects. Following this, each was cross sectioned, mounted in bakelite and metallographically polished as a preliminary to thorough examination under a metallurgical microscope.

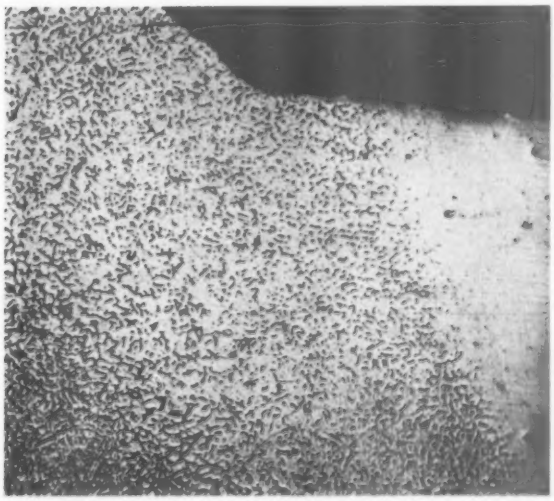

Fig. 1A AISI Type 321 stainless steel inert-gas-shielded arc welded through Solaramic coating

Good quality austenitic weld with randomly dispersed ferrite. Etched electrolytically with 10% chromic acid. 50 ×.

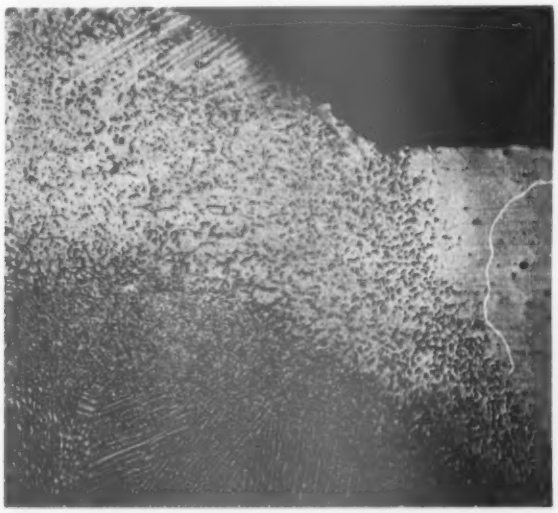

Fig. 2A AISI Type 321 stainless steel oxy-acetylene gas welded through Solaramic coating

Weld quality good, ferrite dispersed in austenitic matrix. Etched electrolytically with 10% chromic acid 50 ×.

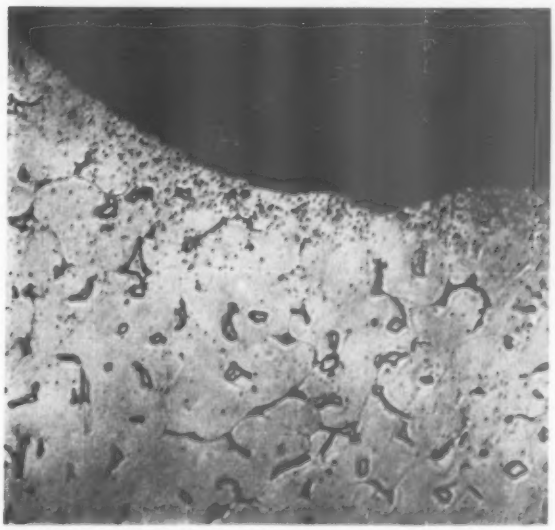

Fig. 1B Higher magnification of Fig. 1A. 250 ×

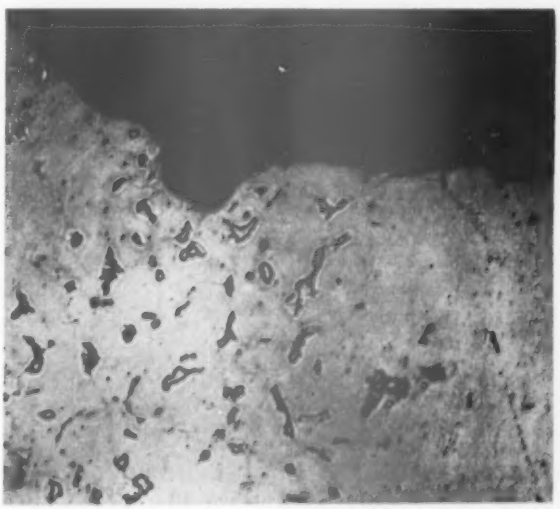

Fig. 2B Higher magnification of Fig. 2A. 250 ×

Detailed examination was first carried out at 100 × in both unetched and etched conditions. Polarized light studies supplemented the more conventional bright field illumination. Weld discontinuities and suspected imperfections were further examined at magnifications of 500 × and 1000 ×.

TEST RESULTS

AISI Type 321 Stainless Steel

All welds were of a uniformly good quality, with no cracking or other injurious discontinuities discernible. No slag inclusions were observed. Figures 1 and 2 illustrate representative weld microstructures made by inert-gas-shielded arc and oxy-acetylene, respectively.

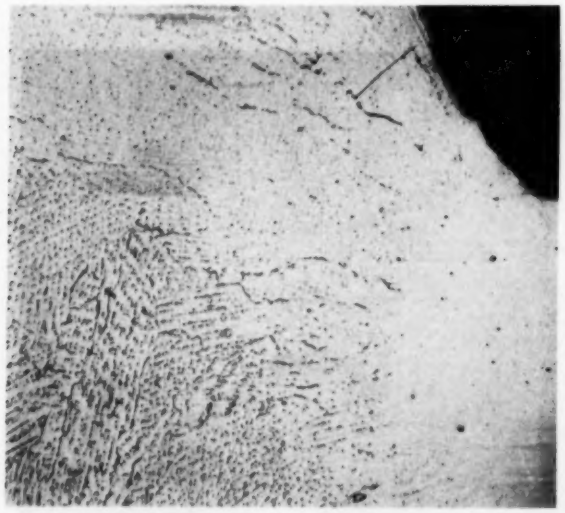

Fig. 3A AISI Type 310 stainless steel welded through Solaramic coating by inert-gas-shielded arc

Poor quality weld due to intergranular fissuring. Etched with Vilella's reagent. 50 ×.

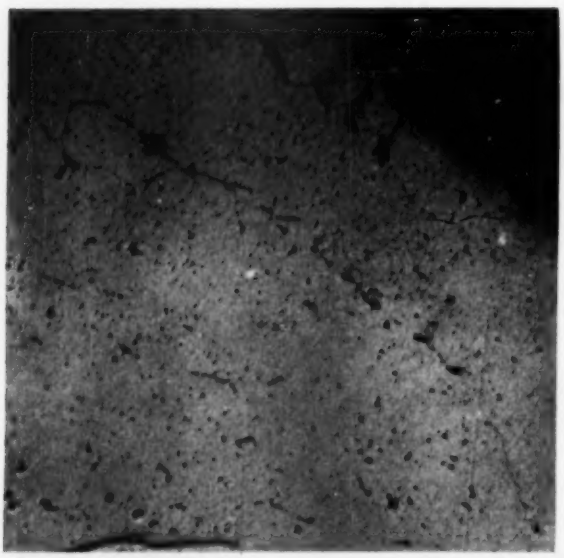

Fig. 3B Higher magnification of Fig. 3A. 250 ×. Note slag films causing fissures

AISI Type 310 Stainless Steel

The welds in this material were generally of inferior quality exhibiting numerous intergranular fissures. Close examination of these fissures under polarized light revealed the presence of a nonmetallic inclusion, probably a silicate. Intergranular fissuring is clearly evident in Figs. 3 and 4, showing the microstructure of of weldments made by the two test methods.

Inconel

As in the case of Type 310 stainless, weldments in Inconel specimens were of comparatively poor quality, exhibiting many intergranular cracks accompanied by nonmetallic inclusions. Microstructure of Inconel weldments are shown in Figs. 5 and 6.

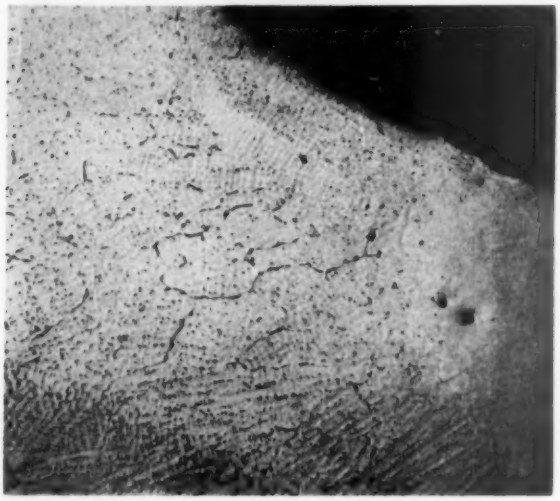

Fig. 4A AISI Type 310 stainless steel oxy-acetylene gas welded through Solaramic coating

Intergranular fissures make weld quality bad. Etched with Vilella's reagent. 50 ×.

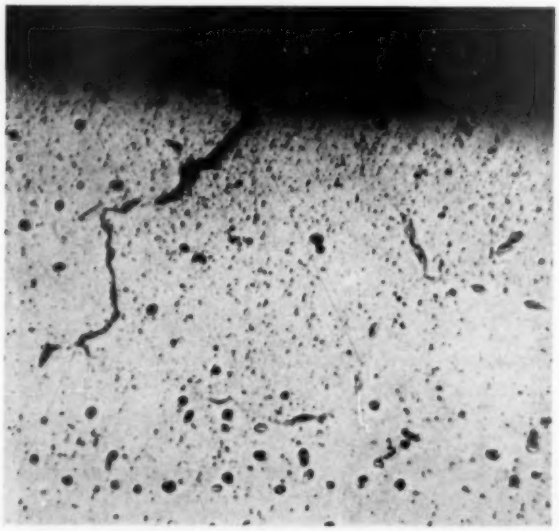

Fig. 4B Higher magnification of Fig. 4A. 250 ×

All welds were defect-free and showed uniformly good quality. There was no evidence of cracks or other discontinuities, nor of inclusions in the weldments. The complex weld microstructure is seen in Figs. 7 and 8.

Sicromo 5S

Due to the air-hardening properties of the alloy, the microstructure of Sicromo 5S weldments is definitely martensitic. However, all welds were of good quality, with no cracking nor inclusions visible under the microscope, as is clearly illustrated in Figs. 9 and 10, showing representative microstructures.

Fig. 5A Inconel welded through Solaramic coating with inert-gas-shielded arc

Low-quality weld due to numerous intergranular fissures. Etched electrolytically with 10% oxalic acid. 50 ×.

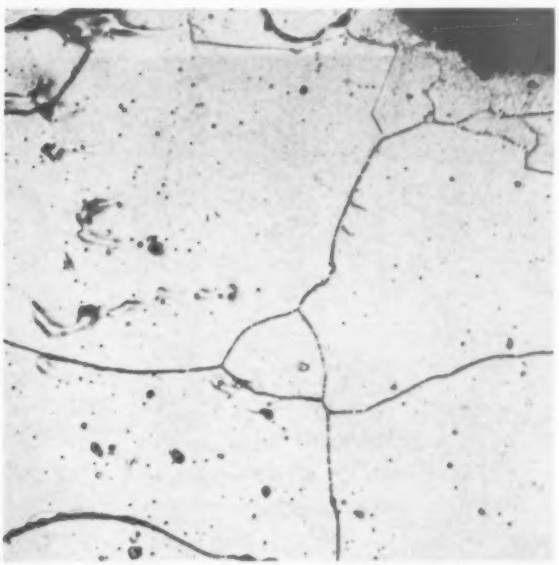

Fig. 5B Higher magnification of Fig. 5A. 250 ×. Note intergranular films surrounding austenitic grains

DISCUSSION

The high-temperature alloys included in the test are those which are more or less standard materials for the fabrications under discussion. Sicromo 5S was included as a low-alloyed material, which type gives promise of proving satisfactory for many intermediate temperature applications, especially when protected with a ceramic coating.

Welding research has shown that certain combinations of elements found in high-temperature alloys and high-temperature ceramic coatings have the tendency to cause hot shortness or brittleness when welding operations are carried out. Generally a combination of high nickel and silicon in conjunction with low carbon produces an unsatisfactory condition for welding.

Fig. 6A Inconel oxy-acetylene gas welded through Solaramic coating

Weld quality poor because of fissuring. Etched electrolytically with 10% oxalic acid. 50 ×.

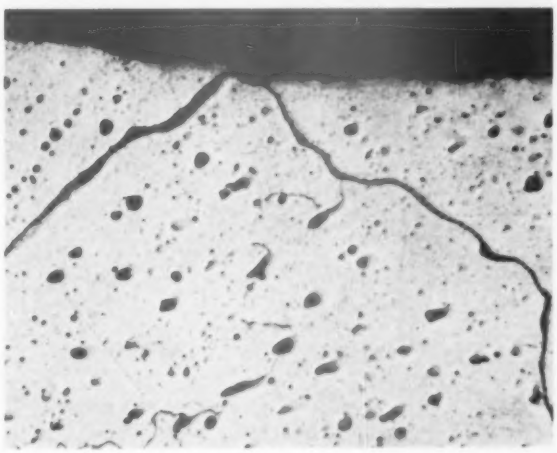

Fig. 6B Higher magnification of Fig. 6A. 250 ×

Apparently the elements columbium (niobium) and molybdenum in the welds modify or eliminate the cracking or fissuring tendency.

Since all of the currently used high-temperature vitreous ceramic formulas contain appreciable amounts of silica, it seems logical to analyze the intergranular cracking or fissuring in the Type 310 and Inconel materials as being due to one of these undesirable combinations and the absence of such defects in N-155 as being due to the columbium and molybdenum content of this alloy.

In reviewing results obtained in the past by welding engineers and research personnel we find that Campbell and Thomas[1] show that AISI Type 310 weldments of a high silicon content are predisposed to intergranular fissures. Carpenter and Jessen[2] similarly show that Type 310 weldments of high silicon and low carbon content have a poor quality due to cracks. They further demonstrate that the cracks apparently are caused by intergranular slag films surrounding the austenitic grains. Examination of these slag films under polarized light indicated the presence of silicates.

Kihlgren and Lacy[3] report that silicon causes weld hot cracking in Inconel and other high nickel-chromium alloys; while Rozet, Campbell and Thomas[4] conclude that high nickel-chromium alloys having high silicon weld metal and a matching low carbon content are especially prone to cracking.

The good quality of weldments achieved on Solaramic-coated AISI Type 321 stainless steel resulted, at

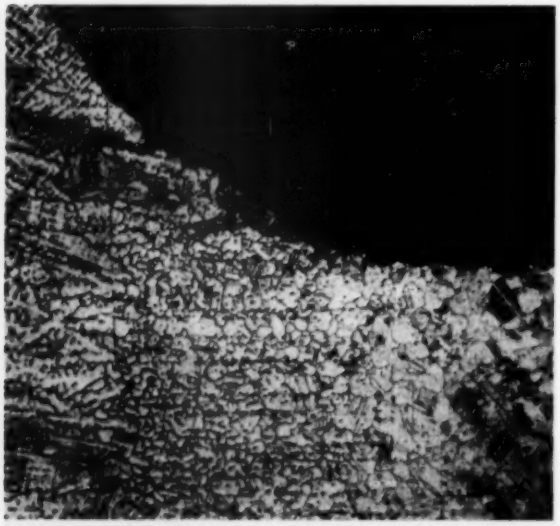

Fig. 7A N-155 welded through Solaramic coating with inert-gas-shielded arc

Weld quality is good, no fissuring or cracks. Etched with hydrochloric acid and hydrogen peroxide. 50 ×.

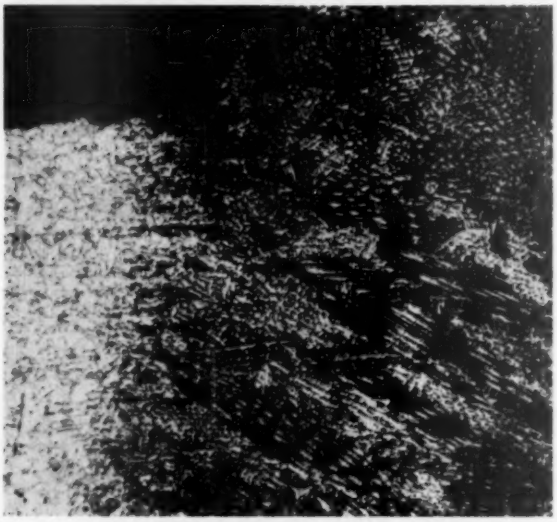

Fig. 8A N-155 oxy-acetylene gas welded through Solaramic coating

Weld quality is satisfactory. Etched with hydrochloric acid and hydrogen peroxide. 50 ×.

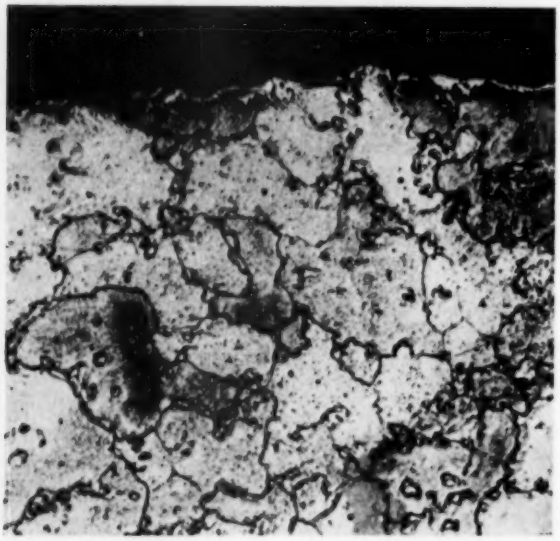

Fig. 7B Higher magnification of Fig. 7A. 250 ×

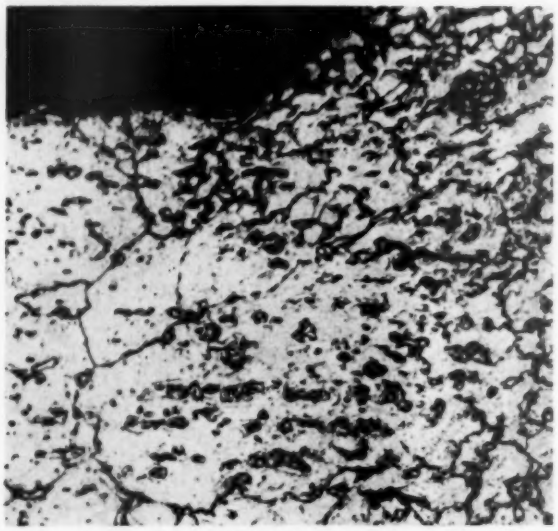

Fig. 8B Higher magnification of Fig. 8A. 250 ×

least in part, from the lower nickel content in the 321 analysis and the presence of ferrite dispersed in the weld microstructure (see Figs. 1 and 2). Thomas,[5] for example, reports that nickel seems to increase the crack susceptibility of chromium-nickel alloys, i.e., the higher the nickel content in these alloys, the greater the tendency to crack. He and others also have found that partially ferritic weld metals are much less crack susceptible than are fully austenitic compositions.

The soundness of weldments on Solaramic-coated N-155 (containing upward of 20% nickel in its analysis) may be attributable to one or all of several factors: The complexity of the weld microstructure, i.e., it is not a single-phase structure (see Figs. 7 and 8); the higher carbon content as compared to Type 310 and Inconel; and the presence of columbium (niobium) and molybdenum in the analysis. Several sources[1, 2, 4] report that an increase in carbon content decreases the tendency toward weld cracking in high chromium-nickel alloys, while Kihlgren and Lacy[3] and others[1, 2, 4] show that columbium (niobium) is effective in counteracting the deleterious effects of such elements as silicon. It has further been demonstrated[1, 2, 4] that molybdenum has a beneficial effect in minimizing the fissuring of welds in high chromium-nickel alloys.

The welding on Solaramic-coated Sicromo 5S was not expected to produce any ill effects such as fissuring. However, this alloy was included in the tests as being representative of some of the low-alloy, martensitic, heat-resisting steels which are being Solaramic coated and substituted for the richer alloys. True to expectations, good quality welds were produced on this alloy.

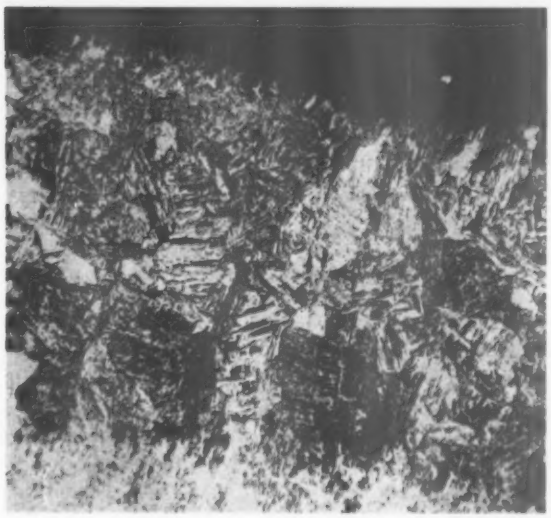

Fig. 9A Sicromo 5S welded through Solaramic coating with inert-gas-shielded arc

Weld quality is satisfactory even though martensitic. Etched with Vilella's reagent. 50 ×.

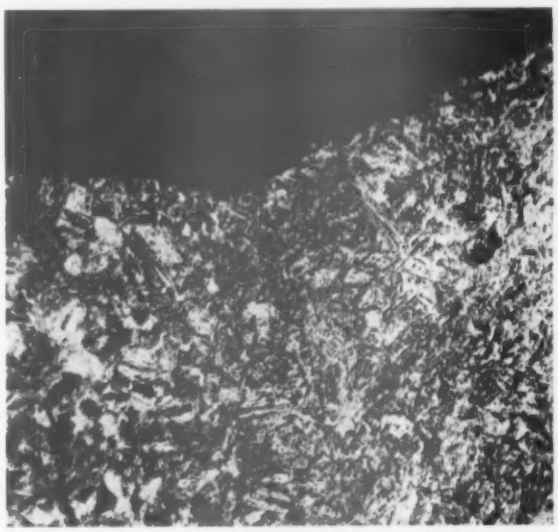

Fig. 10A Sicromo 5S oxy-acetylene gas welded through Solaramic coating

Structure of weld is martensitic, but weld quality is good. Etched with Vilella's reagent. 50 ×.

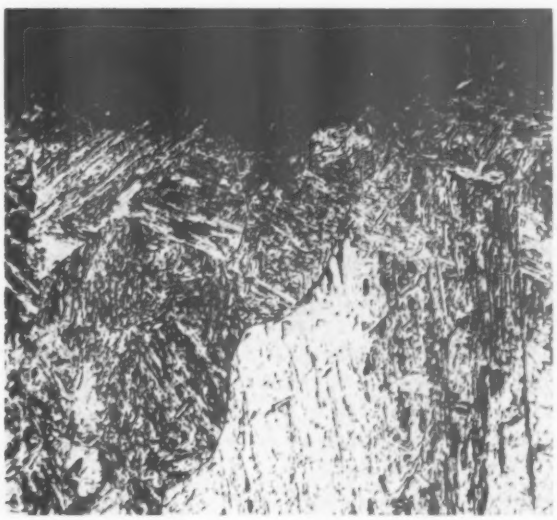

Fig. 9B Higher magnification of Fig. 9A. 250 ×

Fig. 10B Higher magnification of Fig. 10A. 250 ×

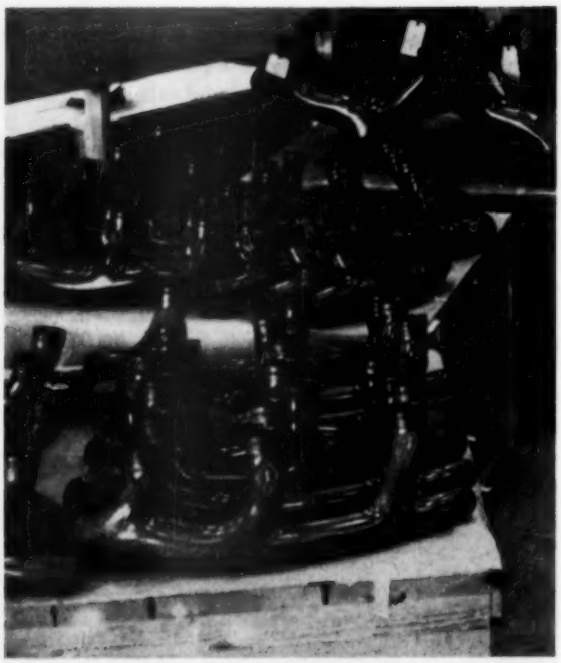

Fig. 11 These are exhaust manifold parts for the DC-4 and B-29 airplanes being ceramic coated in Solar's San Diego plant. These are typical of the types of parts concerning which the author discusses weld repairs

Fig. 12 Turbojet engine combustion chamber liners being ceramic coated with Solaramic at Solar's San Diego plant for the General Electric J47

SUGGESTED REPAIR WELDING TECHNIQUES

It is obvious that the ideal conditions of the laboratory are rarely encountered in the field. However, the successful weldments discussed above should be obtainable by any experienced journeyman welder if the following suggestions are carefully considered.

For oxy-acetylene gas welding of Type 321, N-155 and Sicromo 58, or similar low alloys, the repair area should be cleaned as thoroughly as possible by such means as washing with gasoline, carbon tetrachloride or other cleaning solvent, wire brushing, or application of emery cloth or other abrasive. If a patch is necessary, it should be clean and all burrs should be removed. While the Solaramic coat will give protection against oxidation during the welding cycle, it will have no scavenging action, so that it is desirable to use a good welding flux, on the underside.

Following the welding cycle, the welds and adjacent area should again be wire brushed or otherwise cleaned. A small amount of Solaramic slip may be used as an abrasive in this operation. The area then may be covered with slip, and the torch used to fire the slip into a tough, thin, protective coating.

The process for inert-gas-shielded arc would be similar. Of course, the coating could not be replaced without some means of controlled firing such as is available when gas welding is used. As mentioned previously, metallic arc may be successfully used if fluxing precautions are observed.

When Type 310 or Inconel must be repaired in the field, the ceramic coating should be chipped and brushed away from an area extending at least $^1/_2$ in. around the repair area, for either torch or arc repair, and the underside of the area thoroughly fluxed for torch or metallic arc repair. It should be remembered that the Solaramic coating can be replaced on these alloys by the steps outlined above.

To summarize: With proper care, repair welds can be satisfactorily accomplished on Solaramic-coated fabrications of Type 321 stainless, N-155 and alloys of the Sicromo 58 class. However, when Type 310 stainless and Inconel must be repaired, the ceramic should be removed from the repair area.

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Inert-Tungsten Arc Welding of Stainless Steel Piping

With suitable precautions and proper techniques it is possible to produce a surface on the inside of an inert-tungsten arc-welded stainless steel pipe joint that is smooth and free from obstructions and notches for the material flowing through the pipe

by F. J. Pilia

DURING the past several years considerable progress has been made in eliminating backing rings from welded piping assemblies. This development has been made possible by refinements in inert-gas-shielded arc welding using a tungsten electrode. It is currently possible to produce a surface on the inside of a welded pipe joint that is smooth and free of obstructions, notches, crevices and traps for the material flowing through the pipe. Welds made in this manner do not require finishing, and are satisfactory for handling corrosive liquids, high-pressure and high-temperature steam, fluid metals, food and pharmaceutical products. The purpose of this paper is to describe a controllable technique for producing interior pipe surfaces that are satisfactory for handling these materials.

This technique is limited, at the present time, to fabrication of the Type 300 series stainless steels. Techniques are currently being developed to weld carbon steel, chromium steel and low-alloy steel piping. This welding technique makes it possible for a welding operator and a trained observer to determine the contour and condition of the penetration bead being formed on the inside of the pipe by observing the weld puddle from the outside of the pipe.

The high degree of operator skill previously required to produce this type of joint has been reduced by a significant amount. An operator with average skill can be trained to determine the proper corrective procedures required to produce a satisfactory interior surface in the pipe. The width of the penetration bead inside the pipe can be held to $^1/_8$ in. plus or minus $^1/_{16}$ in., and the height can be held flush plus or minus $^1/_{32}$ in. The radius of the penetration bead can be controlled to $^1/_2$ in. Weld beads within these dimensions present a smooth interior surface with the weld penetration bead blending into the adjacent surfaces of the pipe. It has been found in actual application that the use of this controlled welding technique makes it possible to maintain quality control of a welding operation that was previously dependent solely upon operator skill. This is an unusual situation for manual welding. This controlled operator technique was initially employed to install several thousand feet of stainless steel piping on a military project. An experimental program was established to determine the technique refinements necessary to meet the rigid specifications for quality.

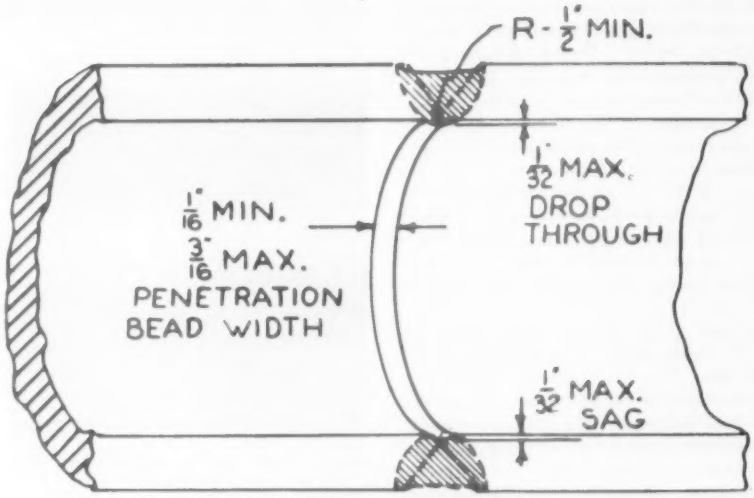

Fig. 1 Specifications for penetration bead contours

A group of samples was prepared to illustrate the types of interior surfaces that could be obtained with Heliarc welding and argon gas backing. When the type of interior surface required for the project was determined, a second group of samples was welded and carefully measured to determine the dimensional limits and contours of the penetration bead. The dimensions shown in Fig. 1 are the averages obtained from these measurements. These dimensions represent practical conditions that can be obtained by an operator properly trained for Heliarc pipe welding.

In the development of the technique, it was found that the height of the penetration bead could be held to within $^1/_{32}$ in. of the nominal inside diameter of the pipe. It was also found that the penetration bead could be consistently controlled from a minimum of $^1/_{16}$ in. to a maximum of $^3/_{16}$ in. The radius of the penetration bead, under all conditions of width and ranging from a flush interior surface to a maximum height of $^1/_{32}$ in., could be held to $^1/_2$ in. This type of penetration bead can be obtained when welding in the fixed horizontal position, the fixed vertical position and when welding in a positioner where the pipe is being rotated. Obviously, welding

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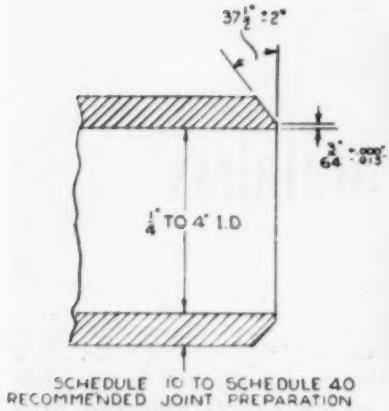


Fig. 1-A Specifications for joint preparation

the pipe in a positioner produces the highest quality welds with a minimum possibility for defects. Rolling the pipe is to be encouraged for all welding operations where subassemblies can be used.

Approximately 60 welding operators were trained in the use of this technique. These operators received an average of 40 to 60 hr of instruction and thereafter were able to produce consistently acceptable pipe welds on pipe sizes ranging from 1/4 to 4 in. in diameter, and wall thicknesses ranging from Schedule 10 to Schedule 40. A reject rate for defective interior surfaces of the welded joints averaged three welds in 500 over a period of 28 months. This unusually low reject rate is attributed to the use of the controllable welding techniques, and to proper training of the operators before assigning them to the job.

Several different welding techniques have been used for stainless steel pipe welding. These methods usually require special bevel preparations, particularly in the overhead portion of the fixed position vertical pipe weld. Varying gas pressures on the inside of the pipe and other variables also complicate the welding operation in the field. The technique discussed in this paper uses a simple bevel preparation, similar to that used for manual arc welding with coated electrodes. Figure 1-A illustrates the proper bevel preparation for pipe sizes up to 4 in. and wall thicknesses up to Schedule 40. A 37½-deg bevel is used with a nose preparation of 3/64 in. The nose preparation may vary from 1/32 to 3/64 in., but should not exceed 3/64 in. for consistent penetration.

Dimensional limits and contour of the penetration bead have now been established. Figure 2 shows the penetration bead obtained on the inside of a rolled weld made in 2-in., Schedule 20, stainless steel pipe, Type 347. The maximum height on the inside of this penetration bead is 1/64 in. Figure 3 shows the outside of the first pass. This weld is made without the addition of filler metal, by

Fig. 2 Penetration bead inside rolled weld in 2-in., Schedule 20 pipe. Arrow shows weld bead overlap

fusing the two pieces of pipe together in the joint. Figure 4 shows the cover pass on 2-in.. Schedule 20 pipe.

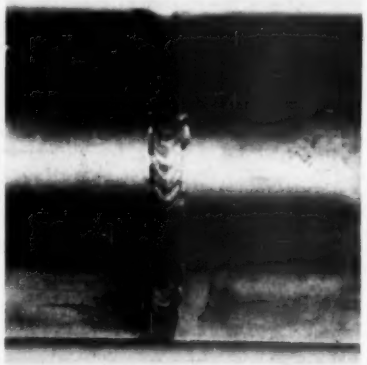


Fig. 3 Root pass outside rolled weld in 2-in., Schedule 20 pipe

Fig. 4 Cover pass rolled weld on 2-in., Schedule 20 pipe

To obtain the smooth interior surface shown in Fig. 2, it is necessary to protect the inside as well as the outside of the weld bead from oxidation. Figure 5 illustrates the effect of argon-shielding gas on the inside of the weld. The joint shown in the upper left-hand corner of Fig. 5

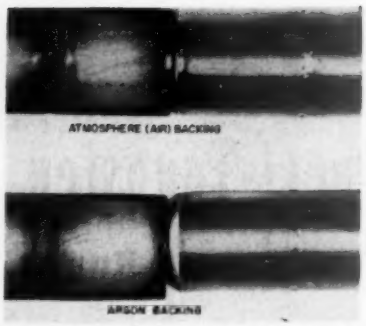


Fig. 5 Effect of gas backing inside pipe

shows the interior surface obtained without the use of argon backing. The joint shown in the lower left-hand corner of Fig. 5 shows the interior surface obtained when using argon backing. The two joints shown on the right-hand side of Fig. 5 represent the exterior surfaces of these same joints. There is little or no evidence on the outside of the pipe to indicate the condition of the interior surface once the weld is completed.

Argon gas backing is the first requirement for obtaining smooth interior surfaces when Heliare welding stainless steel pipe. The inside of the pipe should be protected approximately 1 in. on either side of the joint with relatively pure argon. One volume of air in a pipe must be purged with approximately six volumes of argon before the pipe is ready to be welded. Argon should continue to flow at the rate of 6 cfh during the welding operation. The backing argon should be vented to the atmosphere through ports in the backing mechanism. These ports should be large enough to vent the required volume of argon without a significant pressure inside the pipe. Devices for providing argon backing are usually a set of baffles spaced so that they close the area adjacent to the joint. Argon is fed to the space between the baffles by an argon hose threaded through the pipe. In small diameter pipes, where the use of baffles and hose is impractical, it is necessary to fill the pipe with argon for welding.

TACK WELDS

Tack welds are used to hold the pipe assemblies together in preparation for welding. The tacking operation must be done properly or defects will occur at each tack. Welding skill applied subsequently cannot eliminate the effect of an improperly made tack.

Figure 6 illustrates the proper method of making a tack weld. Argon backing is applied on the inside of the pipe and tack welds are made as small as possible. The termination of the tack weld is made by carrying the weld puddle to the side of the joint, then increasing the travel speed of the torch until the weld puddle dimin-

ishes in size. When the puddle becomes small enough, the arc is broken.

Figure 7 illustrates two types of defects in a tack weld. First, the tack was made much larger than required. This size tack interferes with subsequent welding operations. The arc was terminated by moving the torch too rapidly from the center of the weld puddle. A shrinkage cavity occurred from the top and bottom of the tack. The heavily oxidized interior surface of the tack is the result of failure to use argon backing. Fig. 8 shows

Fig. 6 Typical size and contour of good tack weld

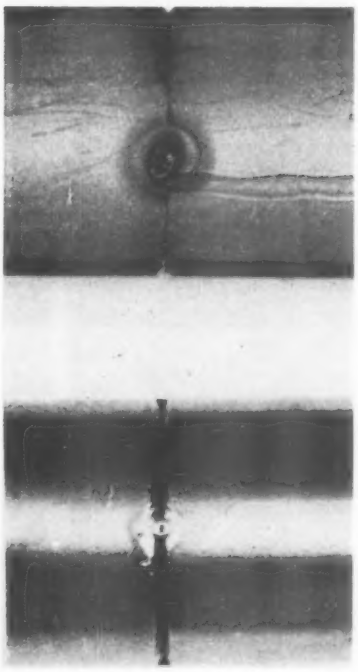


Fig. 7 Defective tack weld made without argon backing shows shrink cavity and excessive size

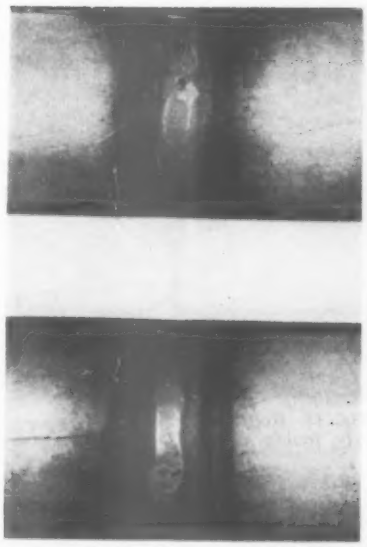


Fig. 8 Tack welds made without argon backing cause defects in finished weld

the effect of an improperly made tack on the interior surface of the penetration bead. The tack welds were made without argon backing. The first pass weld was then made with argon backing. The defects caused by the heavily oxidized surface inside the pipe were not eliminated when the root pass was made. This weld is not satisfactory for sanitary services.

WELDING TECHNIQUE

This welding technique takes advantage of the fact that a fluid weld puddle changes shape when certain conditions are present. The changes in contour of the weld puddle and the associated conditions of penetration bead formation permit the welding operator to "read" the weld puddle. This is the basis of the controllable pipe welding technique. When the arc is struck and placed in the bottom of a vee preparation, a fluid puddle forms rapidly. This puddle bridges the surface of the two parts to be welded. The operator maintains an arc length of approximately $^1/_{32}$ to $^2/_{64}$ in. This is equivalent to an arc voltage of approximately 9 to 13 v when measured between the head of the welding torch and the workpiece. A welding current of 120- to 160-amp DCSP is required for the root pass weld when using the recommended bevel and nose preparation.

When welding begins, the electrode is held stationary and pointing toward the centerline of the pipe. The puddle continues to grow until sharp points are formed on opposite sides of the weld puddle at the bottom of the vee. When these points have developed, the operator advances the electrode in a straight line as dictated by the advancement of the sharp point on the leading edge of the weld puddle. The point formation is shown in

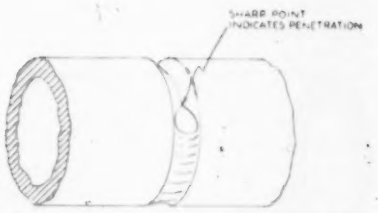


Fig. 9 Contour of weld puddle when penetration is obtained

Fig. 9. This illustration shows the point formation after a portion of the pipe has been welded. As long as this point formation is present, penetration is obtained on the inside of the pipe. If the operator advances the electrode too rapidly, the point on the weld puddle becomes rounded or may even form a re-entrant angle such as illustrated in Fig. 10. The presence of the re-entrant angle invariably signifies the absence of penetration on the inside surface of the pipe.

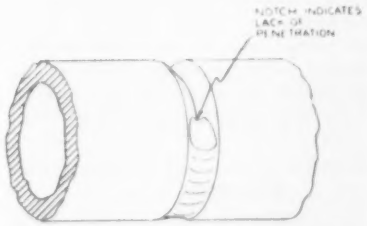


Fig. 10 Contour of weld puddle when penetration is not obtained

There are other tell-tale signs that indicate the amount of penetration and the contour of the penetration bead on the inside of the pipe. When the puddle is initially formed, the surface across the center is raised or convex. When the point formation is obtained on the lead edge of the weld puddle, the operator should observe the convex surface carefully. Soon after the point formation is obtained, the convex surface of the puddle suddenly becomes flat. At this instant, the operator should advance the electrode along the line of weld until this surface again appears to be convex. If the operator responds to these indications rapidly and uniformly, a penetration bead approximately $^1/_8$ in. in width and $^1/_{64}$ in. high will be obtained on the inside of the pipe. If the operator is slow in advancing the weld puddle, and the puddle passes through the stage from a convex surface to a flat surface and finally a concave surface, excessive penetration will be obtained on the inside of the pipe. The weld bead will exceed the maximum $^5/_{16}$ in. width for the penetration bead and the maximum $^1/_{32}$ in. height to the penetration bead. This portion of the technique is basic and must be mastered thoroughly by the operator before proceeding with further instruction. All welds described

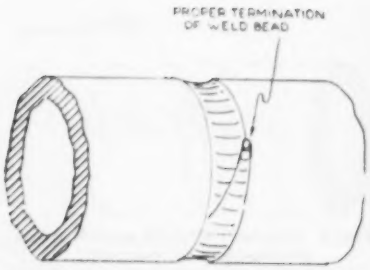


Fig. 11 Proper termination of weld bead prevents crater cracks

in this paper are dependent upon this technique.

When the operator has mastered this technique he will respond to these indicating signs without taking the time to think about them. His reaction to the changing conditions will be normal and effortless. The operator should practice the roll weld on training samples until he can produce three consecutive welds with no defects on the inside surface of the pipe. The welds should be made with the pipe in the horizontal position. The pipe should be rotated manually or mechanically, and the puddle should be located at approximately 10 o'clock on the pipe, welding in an uphill direction before top center.

TERMINATION AND OVERLAP OF WELDING BEADS

Improper termination and pickup of the weld beads account for the few defects that may be encountered when using this controlled technique. Figure 12 shows a properly overlapped and terminated root pass. Notice that the weld bead is overlapped approximately three times the width of the bead, and that the size of the weld puddle is reduced by rapidly increasing the weld travel speed. The weld puddle is directed off the side of the joint so that it may be terminated in a section that is relatively heavy in wall thickness, increasing the chill on the weld puddle and preventing the occurrence of cracks in the weld crater.

Fig. 12 Root pass terminated properly. Note small size of final crater (Outside view)

Fig. 13 Root pass terminated properly inside view. Note penetration bead overlap

Figure 13 shows a penetration bead on the inside of a pipe when the bead has been properly overlapped and terminated. The termination occurs in the upper third of the weld bead.

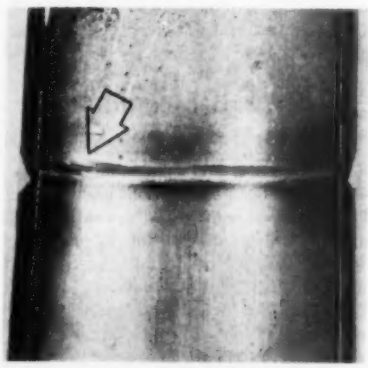


Fig. 14 Pick up of penetration bead on root pass of horizontal weld in 4-in., Schedule 40 pipe

Figure 14 shows the inside penetration bead obtained when a proper pickup of the weld bead is made. Again note that the length of the pickup penetration bead overlap is approximately three times the width of the penetration bead. This ensures a complete overlap and a smoothly blended inside surface on the pipe. This weld was made on 4-in. Schedule 40 pipe in the fixed horizontal position.

Figure 15 illustrates improperly terminated weld beads. The specimen on the extreme left shows what happens on the inside of a pipe when the arc is removed too rapidly from a large weld puddle. A large shrinkage cavity forms on the inside penetration bead. This cavity extends 25 to 30% through the weld bead. In addition, longitudinal and transverse cracking is present. This surface is totally unsatisfactory for sanitary service.

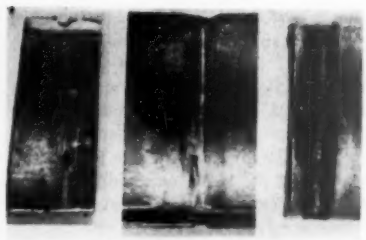


Fig. 15 Defects caused by improper termination of root passes show shrink cavities and cracks

The specimen in the center of Fig. 15 illustrates a similar condition to a lesser degree. A much smaller shrinkage cavity is evident and no cracking has taken place. This is the effect of increasing the welding speed at the overlap, but failing to carry the weld bead off to one side of the joint. The specimen on the right-hand side of Fig. 15 shows the outside of a root pass that has been terminated by removing the arc abruptly from the center of a large weld puddle. Severe longitudinal cracking has taken place along with the formation of a shrinkage cavity.

BLEED-THROUGH

Once the root pass has been completed, and a uniform interior surface is obtained, care must be taken so that succeeding welding operations do not interfere with or destroy the inside surface of the root pass weld. For the root pass, the torch is directed toward the centerline of the pipe, is shown in Fig. 16. When making cover passes on pipe with wall thicknesses of $^1/_8$ in. or less, it is necessary to incline the torch at an angle of approximately 45 deg to a point tangent to the surface of the pipe, as shown in Fig. 17.

Either forehand or backhand welding techniques may be used. In the forehand welding technique, the arc is directed ahead of the weld puddle and filler rod is introduced from the leading edge of the

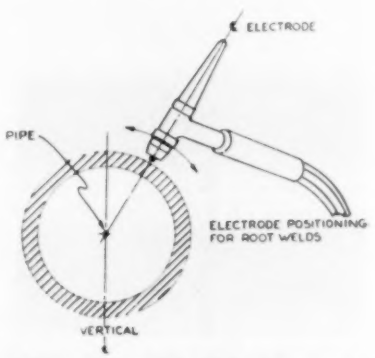


Fig. 16 Proper relation of electrode to pipe center for root pass welds

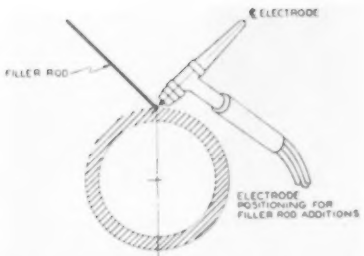


Fig. 17 Proper relation of electrode to pipe for filler rod additions on the second pass

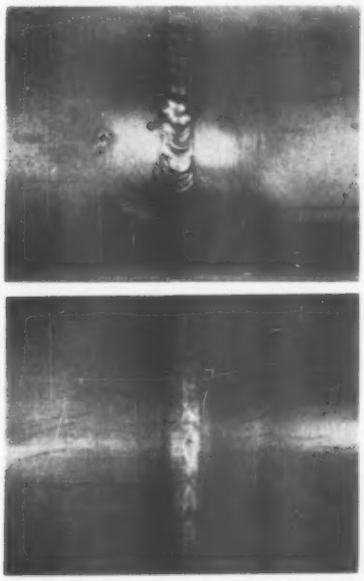


Fig. 18 Poor second pass techniques cause penetration bead rejection. Note irregular contour of penetration bead

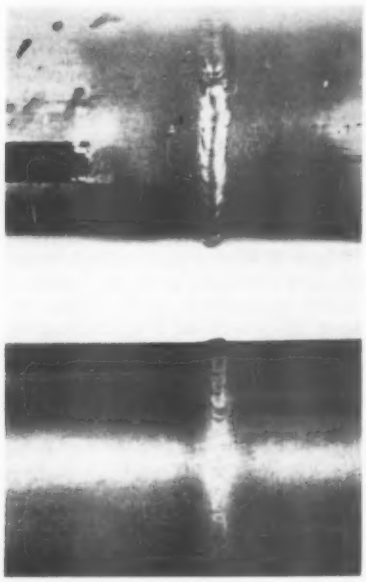


Fig. 19 Good second-pass technique does not impair penetration bead quality

weld puddle. In the backhand technique, the torch is pointed in the direction of the completed weld and filler rod is introduced along the trailing edge of the weld puddler. If the torch is pointed toward the center line of the pipe, such as it would be for the root pass weld, bleed-through will occur on the inside of the pipe, as illustrated in Fig. 18. This bleed-through usually consists of some islands with relatively sharp contours that provide sufficient irregularities on the inside of the pipe to render it unsatisfactory for sanitary services.

Figure 19 illustrates the appearance of the inside of the pipe when the cover pass is properly made. There is a complete absence of bleed-through on the interior surface of the pipe and the penetration bead is regular and uniform. Figures 18 and 19 were made on 2-in., Schedule 20 pipe with the pipe rolled for welding. Figures 20 and 21 show the inside and outside of a weld made in 1-in., Schedule 20 pipe. These welds were also rolled for welding.

Fig. 20 Penetration bead 1-in. diam, Schedule 20 pipe

Fig. 21 Rolled cover pass 1-in. diam, Schedule 20 pipe

Fig. 22 Rolled root pass 4-in. diam, Schedule 40 pipe

Figure 22 shows the outside of the root pass on a rolled 4-in., Schedule 40 pipe. Figure 23 illustrates the penetration bead obtained on the inside of the pipe shown in Fig. 22. Figure 24 illustrates the completed weld shown in Figs. 22 and 23.

Figure 25 shows the outside of a weld made in 2-in., Schedule 20 piping in a fixed horizontal position. Figure 26 shows the cover pass of a weld made in the fixed horizontal position in 4-in., Schedule 40

Fig. 23 Rolled penetration bead 4-in. diam, Schedule 40 pipe

Fig. 24 Rolled cover pass 4-in. diam, Schedule 40 pipe

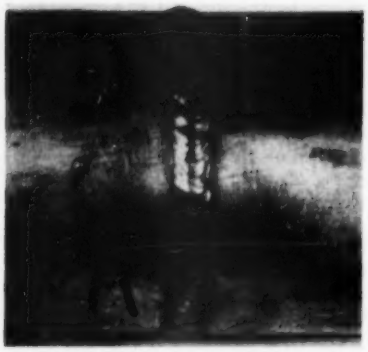


Fig. 25 Horizontal cover pass 2-in. diam, Schedule 20 pipe

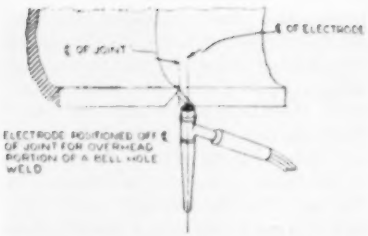


Fig. 29 Proper relation of electrode to joint for overhead portion of a bell-hole weld

Fig. 31 Penetration bead, overhead position, bell-hole weld 4-in. diam, Schedule 40 pipe

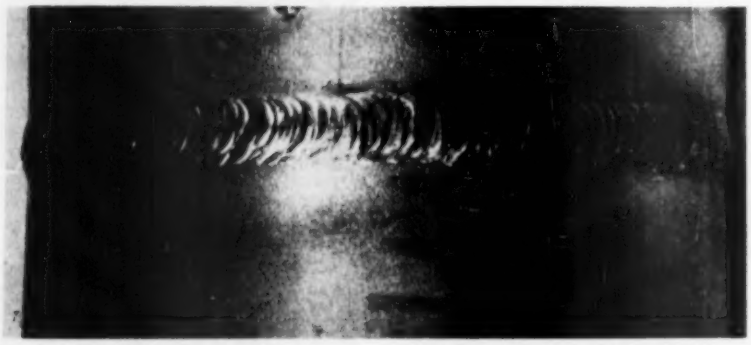


Fig. 26 Horizontal cover pass 4-in. diam, Schedule 40 pipe

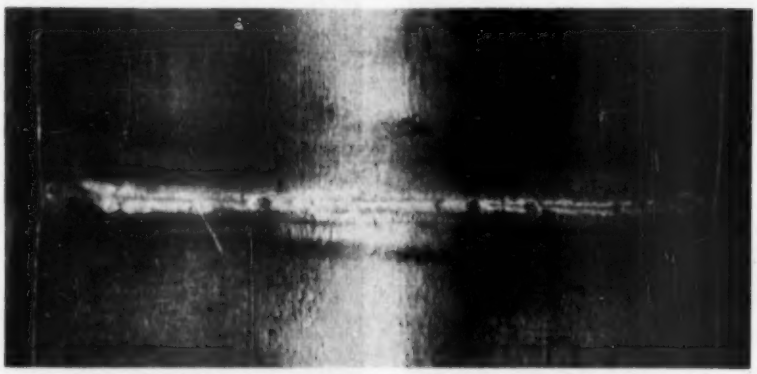


Fig. 27 Horizontal penetration bead 4-in. diam, Schedule 40

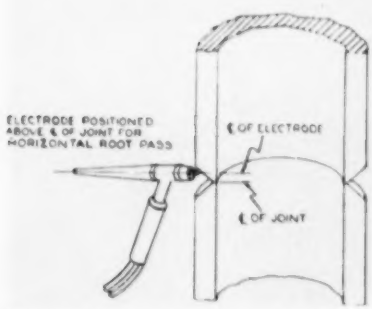


Fig. 28 Proper relation of electrode to joint for horizontal weld

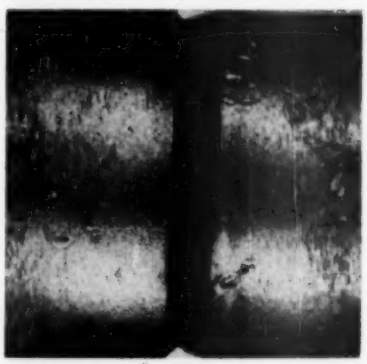


Fig. 30 Root pass, overhead position, bell-hole weld 4-in. diam, Schedule 40 pipe (outside bottom view)

pipe; and Fig. 27 illustrates the penetration bead obtained on the inside of the pipe shown in Fig. 26.

Horizontal and overhead welds require slight modification to the initial technique described for rolled welds. The horizontal fixed-position weld and the vertical fixed-position weld produce a concave penetration bead if the electrode is held directly in the centerline of the joint during welding. It has been found that by positioning the electrode off center, as shown in Figs. 28 and 29, the concave inside surface can be eliminated and a reinforced inside surface can be obtained.

In the horizontal weld, the electrode is offset approximately two-thirds of the width of the joint above the line of the joint. The weld bead is formed on the top side of the joint for the first pass. This same technique is required for the lower third of the overhead position of a fixed-position vertical weld, or so-called "bell-hole" weld. The vertical portion and the flat portion of the welds are made with the electrode on the center line, as described for the rolled weld.

Figure 30 illustrates the outside of the first pass weld made in the fixed-position vertical or bell-hole weld. Figure 31 shows the penetration bead obtained on the inside of the piping shown in Fig. 30. These welds were made on 4-in., Schedule 40 pipe.

The welds shown in Fig. 32 illustrate the outside of the first pass made on 2-in., Schedule 20 bell-hole weld. Note that the weld starts considerably off the centerline of the bottom of the pipe. Figure 33 shows the cover pass applied to the root pass weld of Fig. 32. Figure 34 illustrates the penetration bead obtained on the inside surface of the weld shown in Figs. 32 and 33.

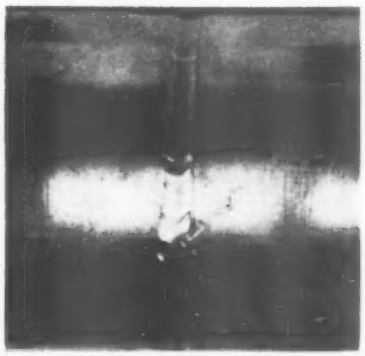


Fig. 32 Root pass, overhead position bell-hole weld 2-in. diam, Schedule 20 pipe (outside bottom view)

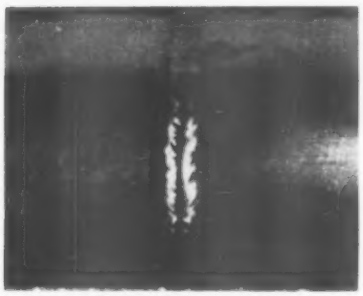


Fig. 33 Cover pass, overhead position, bell-hole weld 2-in. diam, Schedule 20 pipe (outside bottom view)

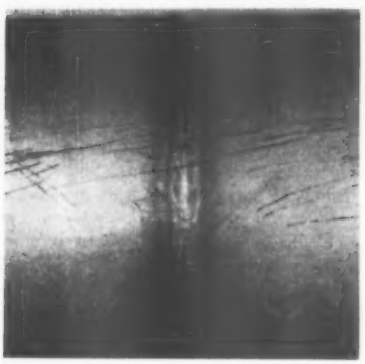
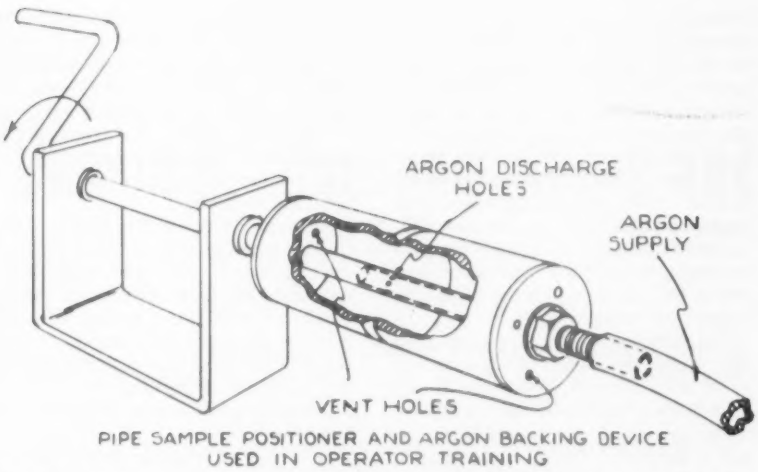


Fig. 34 Penetration bead, overhead position, bell-hole weld 2 in. diam, Schedule 20 pipe (inside bottom view)



PIPE SAMPLE POSITIONER AND ARGON BACKING DEVICE USED IN OPERATOR TRAINING

Fig. 35 Positioner for student training. Argon backing and positioning are combined for simplicity

OPERATOR TRAINING

Quality control and the ultimate in sanitary interior pipe surfaces are the prime advantages of this controlled welding technique. In order to realize the benefits possible from the use of this technique, it is necessary that the operator be properly trained in its use. Basically there are two things that the operator must learn to do in order to use this technique.

1. The operator must recognize the indicating signs in the weld puddle as they develop.
2. The operator must respond to these indicating signs so that proper use may be made of the observations.

It has been found that it is easier and less expensive to train two operators working together as a team than it is to train a single operator. Each weld that is made serves a dual purpose when two operators are trained simultaneously. One operator receives the practice of observing and applying corrective procedures to complete the weld, while the second operator observes the weld and receives the practice of observation.

A small rotating device is required for the operator training program. This device should provide for manual rotation of the pipe, pipe-end closure and argon backing. Figure 35 shows a simple rotating device filling these requirements.

During the training period, welding operators usually prepare 8 to 12 joints per hour. In the interest of economy, it has been found that 2-in. diam, Schedule 20 pipe affords the best training for a wide range of pipe sizes. The pipe nipples to be used for training should be approximately 4 in. long and should be machined beveled on both ends as illustrated in Fig. 1-A. The trainees should not destroy the welded joints after the first pass is made but should return them so that they may be sawed apart and rebeveled for additional use. The nipples are usable until they reach a length of approximately $1^1/_2$ in.

The training program begins with simple instructions on the proper use of the Heliarc torch. A torch of 300-amp capacity is adequate for most pipe welding operations. The torch should be equipped with a $^3/_{32}$-in. diam tungsten or thoriated tungsten electrode ground to a long thin tapering point. Figure 36 illustrates the suggested method of pointing the electrodes.

Each training station should be equipped with a d-c welding power supply of approximately 200-amp capacity, as well as a suitable supply of shielding argon and cooling water for the torch. When the trainee has familiarized himself with the torch and the basic tacking operation, he should then proceed with the practice of the root pass on a rolled joint. The root pass should be practiced until the operator can make three consecutive welds with no defects. Approximately 10 to 15 hr are required by the average trainee to master this first lesson.

In the second lesson, the trainee adds filler rod on top of the root pass weld. The root pass should be mechanically wire

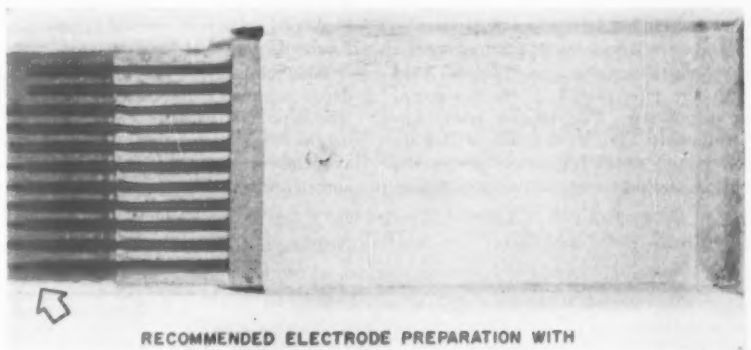


Fig. 36 Electrodes are prepared with long tapered points for pipe welding

brushed on the outside surface to remove all oxide so that it does not interfere with the smooth, uniform application of filler metal for this pass. Figure 19 illustrates the proper relationship between the torch, filler rod and pipe when applying the cover pass. For the cover pass on 2-in., Schedule 20 pipe, 1/16-in. diam filler rod should be used. When the operator is capable of producing satisfactory cover passes without bleed-through on the inside of the pipe, he should prepare three consecutive samples of the root pass plus the cover pass without any defects.

The third lesson consists of placing the pipe in the same horizontal position as would be used for the rolled weld. In this case, however, the pipe remains stationary while the welding operator welds the top half of the pipe. This operation consists of welding the root pass and the cover pass. The pipe is then rotated 180 deg and similar welding is done on the second half of the pipe. This lesson gives the trainee practice in tying in the penetration beads and controlling the travel speed of the torch around the pipe. As a test, three consecutive samples should be made of the complete assembly without any defects before proceeding with the next lesson.

The fourth lesson consists of making a horizontal weld with the pipe placed in a vertical position. In all previous lessons the electrode was held in the center of the joint for the root pass welds. Figure 28 illustrates the proper positioning of the electrode above the center of the joint for the horizontal weld. If the electrode is held on the center of the joint, the weld penetration bead on the inside of the pipe may be depressed or concave. Holding the electrode above the center of the joint eliminates this condition.

This weld is made in 90-deg sections. Ninety degrees is the comfortable limit that an operator can work around a pipe when making a horizontal weld. Particular attention must be paid to the pick-up and termination of the root pass so that the interior surface of the pipe is smooth and free of defects.

In the fifth lesson, filler metal is added to the joint to complete the horizontal weld. The cover pass consists of two stringer beads made with 1/16-in. diam filler rod on 2-in., Schedule 20 pipe.

The sixth lesson consists of making the fixed position vertical, or bell-hole, weld with the pipe placed in the horizontal fixed position. The trainee starts approximately 1 in. to one side of bottom center and welds completely across the bottom and part way up the opposite side of the pipe with the electrode positioned as shown in Fig. 29. The rest of the pipe is welded with the electrode on the center of the joint. This is the same technique that is used for the roll weld or semipositioned weld. Again, three consecutive samples should be made as a test to determine whether or not the trainee has mastered this final lesson.

At the completion of this portion of the training program, the trainee is supplied with nipples of smaller and larger diameters and with pipe of heavier and lighter wall thicknesses. As a suggestion, 4-in., Schedule 40 pipe provides excellent training for large diameter, heavy-wall pipe and 1-in., Schedule 10 pipe provides excellent training for small diameter, thin-wall piping. From 6 to 8 hr of practice are usually required to master these additional pipe sizes and wall thicknesses.

GENERAL

Recommended welding current of 120 to 160 amp for the root pass may appear to be too high to some welding operators currently welding stainless steel pipe. Two distinct benefits have resulted, however from using currents of this magnitude:

1. With currents at this level and with a short arc length (9 to 13 v measured from the head of the torch to the workpiece) the welding operator has a wide range of control of the narrow, deep weld puddle. Corrective procedures may be employed by lengthening the arc to reduce the amount of penetration when required, or by shortening the arc to drive the penetration through the nose of the joint. The surrounding metal adjacent to the joint does not become overheated, and as a result, the cool base metal acts as a chill causing the weld puddle to solidify rapidly. This gives the welding operator additional control.

2. Experience with the Type 300 series stainless steels, and particularly Type 347 stainless steel, has shown that the use of low welding currents and low welding speeds tends to promote the formation of fissures and cracks in the weld beads. The higher the welding current and travel speed and the smaller the weld bead, the less likelihood there is of fissures or cracks occurring in the weld bead

Wide weave beads should be avoided in depositing filler metal because wide beads tend to promote excessive cracking. Welding operators frequently use a weave bead as a final cover pass to improve the appearance of a weld. The weave bead should be avoided unless it adds materially to the sanitary condition of the weld.

3. Welding generators that afford a range of adjustment on the open-circuit voltage of the generator should be used as power supplies. The generators should be adjusted for maximum open-circuit voltage so as to produce the steepest possible volt-ampere curve obtainable from the generator. With the steep volt-ampere curve the effect of normal variations in arc length are not reflected in appreciable variations in heat input to the work. This is important since it helps to minimize the effect of variations normally encountered in manual welding.

4. Tungsten electrodes are used in an unconventional manner for stainless steel pipe welding. Electrodes are normally operated at the highest possible current density in order to obtain maximum arc stability from the electrode. In actual practice, however, it has been found that when using 1/16-in. diam electrodes, with the recommended current range, excessive electrode contamination results in excessive tungsten deposits in the weld puddle. Considerable tungsten is consumed when contamination takes place and adjustments of the electrode are frequently required. The problem is materially reduced by using a 3/32-in. diam electrode, ground to a long needlelike point. Electrodes prepared in this way resist contamination to a much greater degree than the standard 1/16-in. diam electrodes. When contamination does occur, appreciably less tungsten is transferred to the fluid weld puddle.

SUMMARY

Heliarc welding has made possible the elimination of backing rings from welded piping assemblies. Controllable welding techniques have also made it possible to produce sanitary surfaces on the inside of welded piping without grinding or post-weld treatment. Controllable Heliarc welding techniques have also made possible a high degree of quality control where required for critical sanitary piping services.

While this technique refers specifically to the Type 300 series stainless steel, investigations are being carried on to develop techniques of a similar nature for low-alloy chrome steels and carbon steels. Nickel, Monel and Everdur respond to a slight modification of the technique described. Variations in procedure are necessary with different materials because of the difference in heat conductivity of the materials.

Spot Welding of Aluminum, Aluminum Alloys and Steel

Results of tests to establish welding techniques and schedule which will produce satisfactory welds with special emphasis on the three variables: force, time and current

by W. J. Wilson

RESISTANCE spot welding of the common aluminum and aluminum alloys, steels, stainless steels and other materials, as applied to the fabrication of aircraft, jet engines, guided missiles and commercial products, is relatively easy to accomplish with a reliable welding schedule and equipment which is capable of fulfilling the schedule requirements.

The wide variety of products welded, the quality and size of weld desired and the characteristics of the equipment in the application of current, force, time and other variable factors, influence the range over which spot welding may be accomplished. It is possible to produce similar welds using a relatively wide spread combination of machine settings. This fact has led to considerable controversy on the subject of welding technique and machine schedules.

In the spot welding of commercial products, extreme flexibility is generally practiced, while in the spot welding of structural and highly stressed components, this flexibility is considerably restricted to meet specific requirements for weld strength, size, structure and quality as defined by the customers' specifications. However, a recent survey of aluminum spot welding practices indicated that this apparent narrow range is very much wider than that commonly accepted by industry. In the compilation of welding schedules submitted by many industries, it was discovered that there was little similarity of practice. This definitely points out two things: first, that most aluminum alloys can be welded over a wide range of machine settings; second, that the need exists for some standardization to provide a guide for the initial establishment of machine schedules, and when required, for machine certification.

In the initial preparation of *Recommended Practices for Stainless Steel Spot Welding*, the industry was solicited to supply data. Actually, relatively little information was available and there was considerable variation in the information submitted. Therefore, it was necessary to conduct a program of tests in order to establish a desirable set of machine schedules.

The compilation of data for aluminum spot welding followed a similar pattern. Industry was requested to supply data. The information supplied varied tremendously and in many cases was not complete. In general, the information was essentially machine settings and lacked data relative to weld nugget diameter, actual current, weld strength and other important factors. Again the varied range of force, time and current was emphasized by the data submitted and it was again necessary to initiate a program of conducting tests to establish schedules which would produce satisfactory welds. Therefore, it should be remembered that spot welding can be accomplished over a very wide range of machine settings, depending upon the influencing factors, and adjustment must be made to satisfy varying conditions. Furthermore, a comprehensive understanding of the fundamental variables is of essential importance and will therefore be reviewed in detail. In adjusting a machine to spot weld a given combination of material, the three important fundamental variables are considered in the order of force, time and current.

WELDING FORCE

The welding force, applied by the electrode at the weld holds the various interfaces in intimate contact during the welding cycle, and must be of sufficient magnitude to localize the area of current flow, reduce resistance between electrodes and sheet surfaces, and minimize internal weld defects. In general, low-strength material alloys require low welding force and conversely, high-strength material alloys require high welding force. Commercial aluminum products such as light reflectors or baffles and likewise stainless steel and steel aircraft and commercial products are commonly welded on single force machines. However, aircraft components of the structural alloys such as 75S and 24S Aluminum are generally welded on double force machines which apply force during welding, which is followed rapidly by the application of approximately twice as much force to forge the weld nugget and eliminate internal defects.

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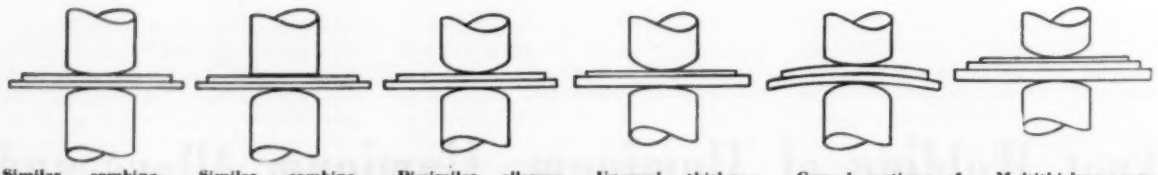
Similar combinations, similar radius
Similar combinations, radius to flat for flush surface
Dissimilar alloys—Uniform thickness, larger radius tip against the higher resistance alloy
Unequal thickness combinations, larger radius tip against the heavier gage
Curved sections of similar thickness, larger radius tip against the outside of the curve
Multithickness combinations, larger radius tip against the heavier outside gages

Fig. 1 Heat Balance

In many cases, particularly on light gages, this forging force is not absolutely necessary but is generally used because it is the easiest way to accomplish the objective. The need for the elimination of internal defects is established by customers' specifications which indicate the size and extent permissible for such defects.

WELD TIME

Weld time is considered to be the actual time during which the welding or secondary current flows. The duration of current flow must be sufficient to affect the weld without excessively heating the surrounding metal. In spot welding aluminum, shorter time is used than in the spot welding of steel or stainless steel. The duration of weld time is controlled for conventional a-c machines by the number of cycles used, and for stored energy machines by altering the wave form by changing the inductance, capacitance and voltage. The amount of weld time for a given combination depends on the joint thickness and the material to be welded.

WELDING CURRENT

The welding current is that current flowing for a given time which provides the energy necessary to consummate the weld. It must be of sufficient magnitude to produce the desired weld, and higher currents are required for aluminum than for steel or stainless steel. The welding current on conventional a-c machines is varied by transformer taps or phase shifting and on stored energy machines, by altering the wave form.

WELDING TECHNIQUE

The technique of welding is in the broadest terms, "The selection and application of the variables, force, time and current and the faithful reproduction of each variable to insure welds of uniform quality on any machine operating on the same welding principle." The approach to this problem varies considerably throughout the country and in the different industries. Nevertheless, the basic fundamentals apply. Detail procedures of aluminum spot welding machine adjustments for individual machines have been developed and published in the AWS *Recommended Practices for Spot Welding Aluminum and Aluminum Alloys*, and need not be repeated here. However, the following general procedure is common to most applications:

For steel, stainless steel or aluminum, the first consideration is electrode size, shape and force. Select the proper electrode diameter and contour. Contour selection for unusual combinations of dissimilar aluminum alloys and/or gages, warrants special consideration. (Figure 1 illustrates various conditions.) Once the contour has been provided, the welding force for a given combination may be selected. Thinner gages require less welding force than the thicker gages. The approximate magnitude of the weld force may be determined from the published schedules. A greater or less amount of force may be used, depending upon conditions. In the case of aluminum, adjustment may be made for forging force and proper timing of the force cycle established. When forge force is used, it is very important that it be applied at the correct time in the heating and cooling cycle of the weld. If applied too soon, weak or "dud" welds will result. If applied too late, no benefit will be derived from the forging action. Proper timing of the forging force may be determined by a recording oscillograph or similar instrument or by trial and error. Once the electrode contour, weld forge, forging force if used and force cycle have been determined, the basic factors have been established.

It is now necessary to cause the required amount of current to flow for the required time. The time for which the welding current flows is next established and the welding machine is adjusted to provide for the correct duration of time, the values of which may be determined from the published schedules. This time can be further adjusted by alteration of the wave shape, changing the rate of rise, or postheat current.

The next step is to adjust the magnitude of the current to a required value. It is not necessary to know the magnitude of this current, although it is sometimes helpful. Common procedure is to start with a low value and increase the current until the desired weld strength and size are obtained. In many commercial applications this is accomplished by increasing the magnitude of the current until weld expulsion occurs and then reducing the magnitude slightly, testing for weld strength, quality, size and consistency to insure the desired product.

A brief review of these steps consists of the following procedure:

Insert electrodes of correct contour in the machine, apply the desired welding force, checking for consistency with a force gage; adjusting forge time and force cycle and setting the controls to provide the desired weld time. Then, starting with a low value of current, make and test single spot welds in shear, twist, peel or macro, increasing the current gradually until the desired weld is obtained. In some cases, it may be necessary to readjust time.

Obviously, many refinements can be applied to this basic procedure. For example, in the case of dissimilar gage or material combinations, it may be desired to obtain the very optimum setting to insure consistency and alleviate production difficulties. In such cases it might be desirable to experiment, holding time and current consistent and varying the pressure, or, holding current and pressure consistent and varying time. Further refinements include variation in electrode material, contour, diameter, postheat current, rate of rise and other factors. All this discussion should be considered very fundamental and that is the objective, because the accomplishment of welding aluminum, stainless steels and steels is not nearly as difficult as has been indicated. The previous discussion has attempted to show how to achieve the common weld. In many cases, however, it is the unusual condition which causes trouble. Examples of such cases are the spot welding of thin stainless steel to heavy mild steel, spot welding of thin 24ST clad material to thick 52S0 material, the spot welding of multithickness combinations such as thin to thick to thin, and other similar conditions.

DEFECTS AND CORRECTION

Frequently the question arises: "What to do to eliminate certain defects when they occur?" The problem of detecting and eliminating weld defects is conducive to the production of good welds, hence will be discussed in some detail.

Internal cracks, or voids (see Fig. 2), in the weld nugget are fairly common. Such defects are revealed by sectioning the weld and making a macro or by radiography. In many cases, such defects are not objectionable and their acceptance depends upon customer specifications. These defects can be eliminated or minimized by increasing the welding force, utilizing forging force where required, and insuring correct application of the forging force, decreasing the rate of current rise where possible, maintaining proper electrode cooling and eliminating electrode skidding and excessive penetration.

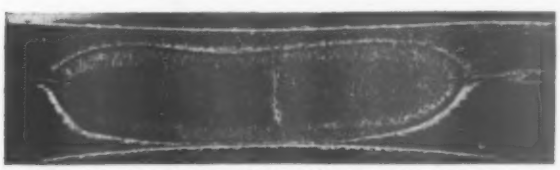

Fig. 2 Internal cracks

Excessive penetration (see Fig. 3), where the weld nugget penetrates too far into either one or both of the two outer sheets, is also responsible for cracks in the surface of the weld which may be observed visually, and in some cases voids within the weld nugget. Insufficient penetration (see Fig. 4), which results in weak or inconsistent welds, may be corrected by increasing the welding current or timing or decreasing the electrode contour radius.

Surface burning is another common defect and is due to excessive heating on the contact surfaces of the electrode and the work. This can be eliminated or mini-

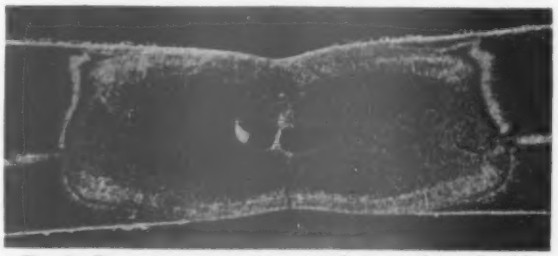

Fig. 3 Excessive penetration, surface cracks and voids

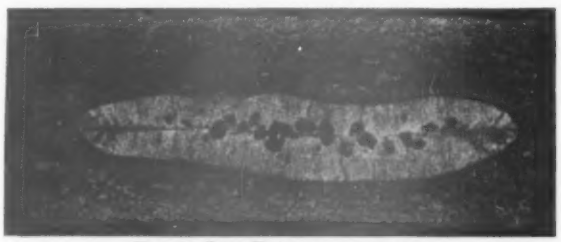

Fig. 4 Insufficient penetration

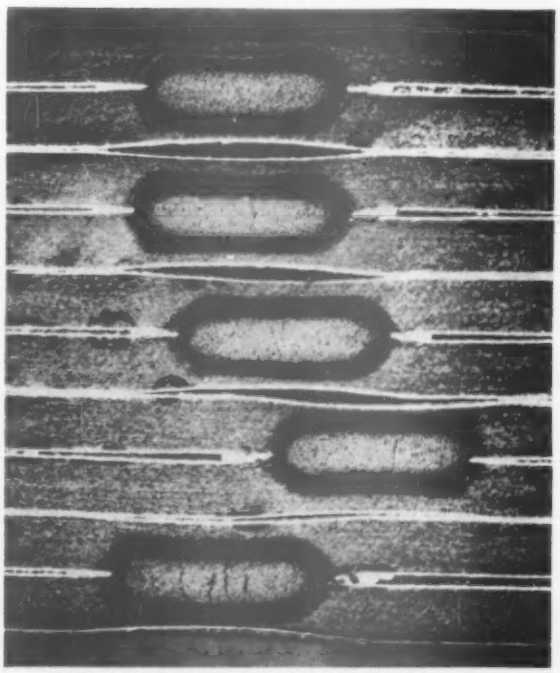

Fig. 5 Spot welds with excessive weld expulsion

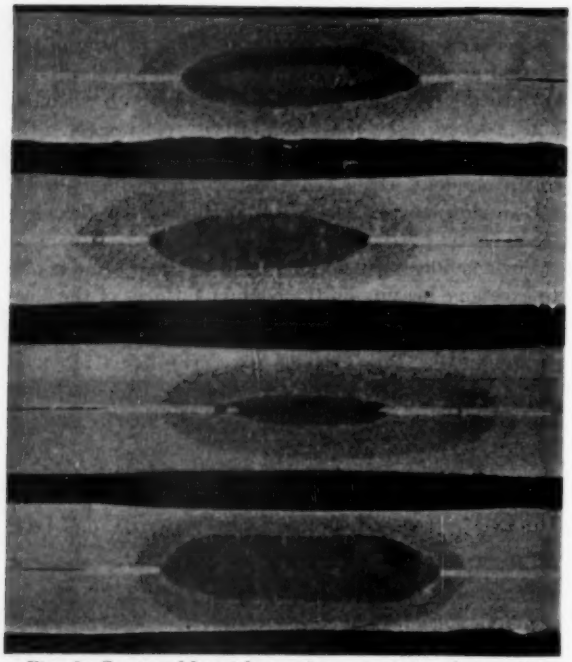

Fig. 6 Spot welds with varying amounts of porosity

mized by cleaning the electrodes or improving the surface cleanliness of the metal, proper electrode cooling, changing the electrode contour, using electrode material of higher conductivity, increasing the welding force, reducing the weld time and current and eliminating electrode skidding.

Excessive indentation may be minimized by reducing the welding force, increasing the radius of the electrode contour, or reducing the welding current.

Sheet separation is frequently caused by improper fit-up of parts. Satisfactory fit-up of parts will generally eliminate the condition, although it may be necessary to reduce the welding force, change the electrode contour or to correct such factors as tip misalignment, excessive weld time or current.

Weld expulsion (see Fig. 5) is a common defect generally referred to in the shop as "spit." Correction can generally be accomplished by increasing the welding force reducing the welding current, cleaning the material or eliminating electrode misalignment or skidding.

Unsymmetrical welds in the horizontal and vertical planes of the weld nugget may be corrected by proper surface preparation, good fit-up of parts, proper electrode contour and correction of electrode misalignment. Frequently, however, dissimilar gage thicknesses cause unsymmetrical welds and experimentation with electrode contours is necessary to minimize the condition.

Porosity (see Fig. 6) is another common defect and may generally be corrected by increasing the welding force and when forging force is used, adjusting the forging cycle, adjusting the rate of current rise and increasing the weld time.

There are other less common defects and also some conditions which are misconstrued as defects. An example of this is Eutectic Stringers (see Fig. 7) in some aluminums and heat-resistant steels. 52S aluminum and high nickel alloy heat-resistant steel are good examples. The stringers occur in the base metal and nugget, respectively, and if improperly etched these stringers appear to be voids or cracks. However, if properly etched these conditions can be easily shown to be free of cracks.

In the previous discussion it was shown how welding schedules were established, the procedure to adjust machines and how to eliminate defects. This instruction must be supplemented by welding schedules to provide a starting point for standard welding practice. As previously mentioned, the industry as a whole is welding various materials over a wide range of the variables and on a number of different types of machines made by a large number of manufacturers. This confirms the fact that standard schedules would be beneficial to industry. In the case of low-carbon steel products it was found that the widest range of settings are employed. However, in that wide range, there is a

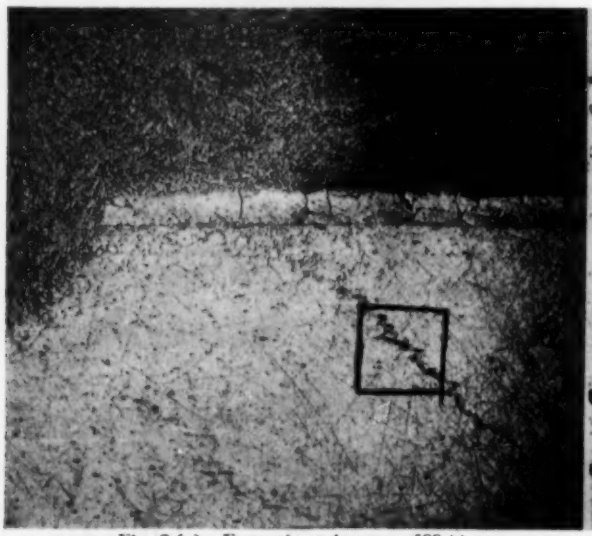

Fig. 7 (a) Eutectic stringers. 100 ×

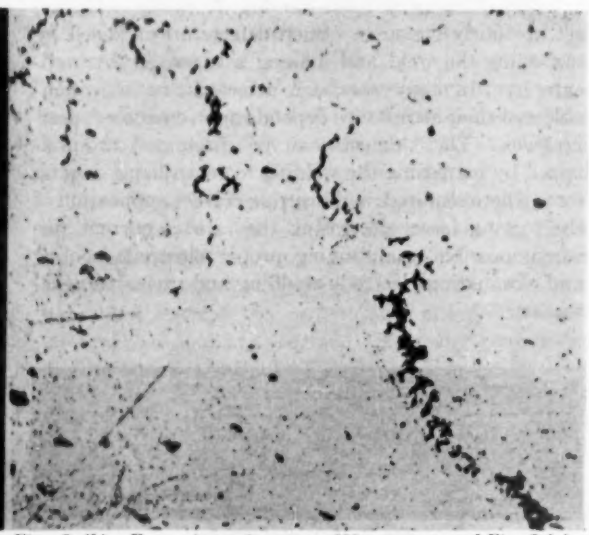

Fig. 7 (b) Eutectic stringers. 600 × mag. of Fig. 7 (a)

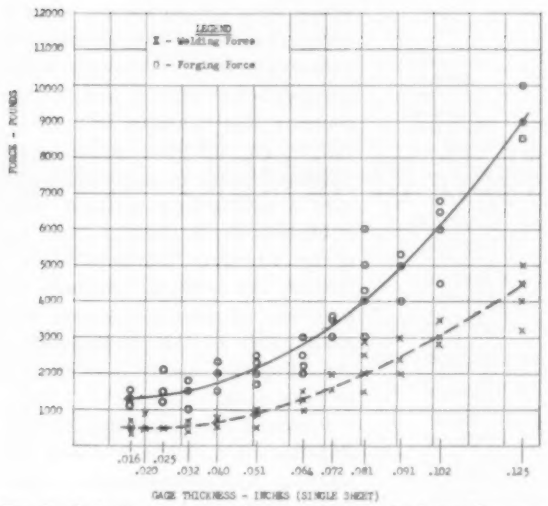

Fig. 8 Relation between force and gage thickness for spot welding two equal combinations of 14ST, 24ST and 75ST clad aluminum alloy

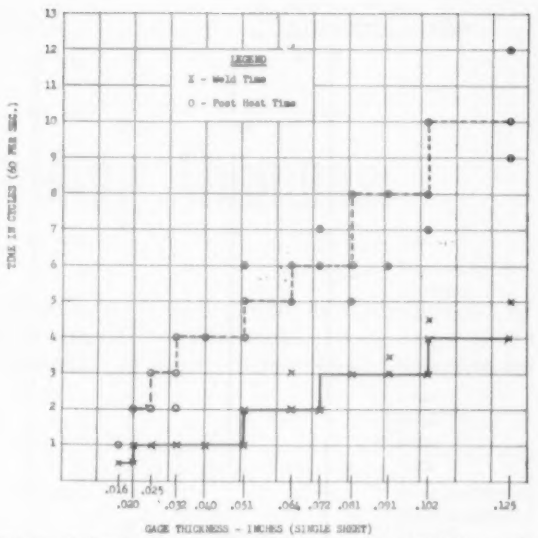

Fig. 9 Relation between weld time and gage thickness for spot welding two equal combinations of 14ST, 24ST, and 75ST clad aluminum alloy

more narrow range which will provide quality welds under more economical and practical conditions. Relatively, the same condition exists for stainless steel, heat-resistant steels and aluminum alloys. In each case, the utmost endeavor should be made to operate within a range that will most consistently reproduce the desired result, with the least amount of testing and maintenance. It would be completely impractical to prepare welding schedules for all the possible combinations of materials or alloys, thicknesses, surface preparation, fit-up and geometry of parts, shop conditions and the many other factors which can influence welding. However, the AWS has published *Recommended Practices for Resistance Welding of Aluminum; Low Carbon Steel and Stainless Steel*, and should be referred to for basic information. Personnel responsible for setting up machines to accomplish welding should use these Recommended Practices as a guide. In most cases they will provide exactly what is needed. In other cases they must be modified for existing conditions. For example, in the welding of teakettles for the housewife and tip tanks for the wings of our jet planes, the manufacturer desires a flush surface on the exterior. In the case of the teakettle for appearance; in the case of the tip tank for aerodynamic smoothness. To accomplish this a flat electrode is selected for the exposed surface and the contoured electrode for the unexposed side. As another example, it might be expedient from a production standpoint to establish a given machine setting that will work equally well on two or more gage combinations so that it is not necessary to readjust the machine as changes in gage combination are encountered in one part. Many other similar examples could be cited but these are sufficient to illustrate the point. Since welding schedules are a guide, modifications must be made as required and it is unlikely that we will ever be able to prophesy all the various conditions that will be encountered.

The transition of welding schedules from the early war years of 1942 until the present has been quite interesting. The pendulum has been swinging from single-phase ac to stored energy, to three-phase frequency converter and rectifier, to single phase with slope control machines. In addition, we have the variation between the manufacturers for a given type of machine. During this period it has been very difficult to maintain any degree of standardization. However, it is hoped to avoid this difficulty in the future by supplements to the Recommended Practices.

There is also one additional major factor which must be considered in welding schedules; that is, the customer's requirements. In the case of aircraft and compo-

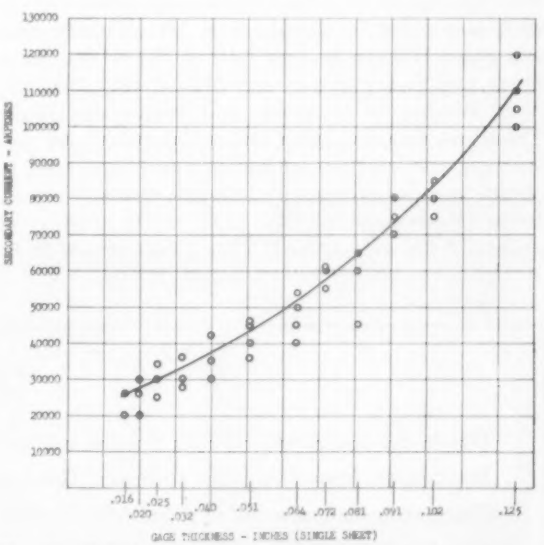

Fig. 10 Relation between secondary current and gage thickness for spot welding two equal combinations of 14ST, 24ST and 75ST clad aluminum alloy

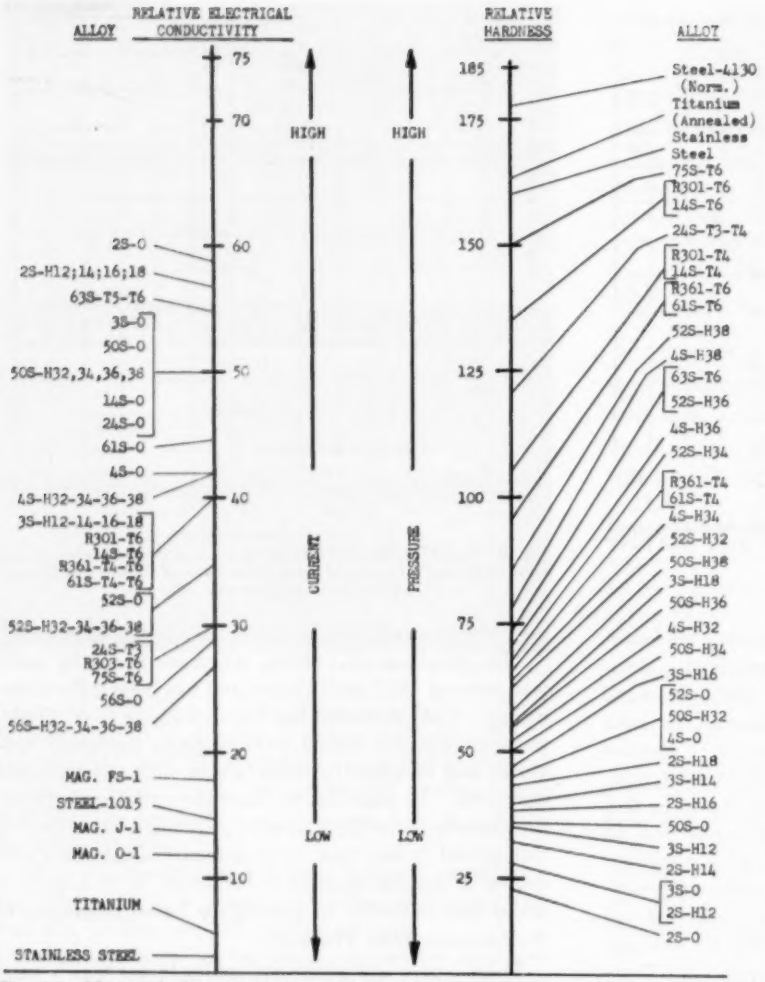

Fig. 11 Material characteristics and their relationship to welding current and pressure

nent equipment these requirements are defined in the applicable Military Specifications MIL-W-6858, Spot and Seam Welding of Low Carbon Steels, Austenitic Steels, and Nickel Alloys; and MIL-W-6860, Spot and Seam Welding of Aluminum and Magnesium Alloys. These specifications define the weld quality and weld strength, and establish production control procedure to obtain these requirements. In addition, many private industries have specifications of their own defining the quality of the weld desired. The other extreme exists where there are no specific requirements of the weld other than to provide attachment. Obviously, where specifications form a part of the contract they must be adhered to. Where no definition exists, good judgment must be exercised to insure a satisfactory product. The published Recommended Practices of the AMERICAN WELDING SOCIETY contain the welding schedules for a number of metals that will produce welds capable of meeting or exceeding the quality requirements of these codes.

Figure 8 illustrates the relationship between electrode force and material thickness for certain aluminum alloys. Other alloys may require different values. The curve is an average of several values and indicates the range available. The establishment of force requirements is the first consideration and should follow a general pattern.

Figures 9 and 10, respectively, illustrate the relationships between time, secondary current and material thickness. Again the spread of individual values through which the average curves are drawn indicates the ranges.

In many cases, variations in weld time and current, and postheat and current are required for different manufacturers' machines. Since dissimilar thickness and material combinations are most frequently encountered, this information should be valuable in the establishment of schedules for such conditions.

As an additional guide for the establishment of welding factors, Fig. 11, showing material characteristics and their relationship to welding current and pressure, may be used. This indicates required pressure increases with relative hardness and required current increases with relative conductivity. This is not a cure-all but simply a guide, and similar graphs may be of use to industry.

Notice

Due to the Christmas Mailing Volume we have been cautioned not to send out our Buffalo Hotel Reservation Form just prior to then. Therefore they will be mailed immediately after Christmas. Processing and acknowledgment from Buffalo Hotels will commence Feb. 15, 1954 as previously scheduled.

Quality Control in Spot Welding Aluminum

Acceptable end-product results from establishment of satisfactory limits of operation for each phase of process and from the maintenance of operation within these limits

by Floyd H. Matthews

INTRODUCTION

QUALITY control may be defined as the system or procedure that insures an acceptable product. The over-all success of the quality control system may be presented in a chart as shown in Fig. 1 which illustrates the ratio of rejected parts to those parts that are accepted. This quality control chart indicates the over-all functioning of the many systems that contribute to an acceptable end product. It also indicates any general laxity on the part of shop supervision in maintaining the quality of the product. Unfortunately, if a high ratio occurs on the quality control chart, the damage has already been done. To reduce this ratio it is necessary to establish a number of quality control systems; one over each phase that affects the welding process. Quality must be "built-in."

The following factors affect the quality of the finished product: The equipment used to weld the parts, the cleaning method used for cleaning the parts prior to spot welding, the parts being welded, the machine settings or welding schedules developed for welding the parts and the personnel doing the actual welding.

EQUIPMENT

The initial equipment qualification tests as required by MIL-W-6860 establish the ability of a spot-welding machine to make acceptable welds in a consistent manner in the minimum and maximum machine settings to be used in production. However, there are other requirements that must be fulfilled. It is not reasonable to expect to establish process control limits that are closer than the machine's capabilities if satisfactory production is to be obtained. Therefore, the inconsistencies in machine operation must be controlled if the operator is to maintain the weld strength, consistency and quality requirements within the limits of adjustment of the machine controls allowed by specification.

Floyd H. Matthews is the Assistant Tool Design Manager of the Boeing Airplane Co., Seattle, Wash.

Presented at the National Spring Meeting, AWS, Houston, Tex., June 16 to 19, 1953.

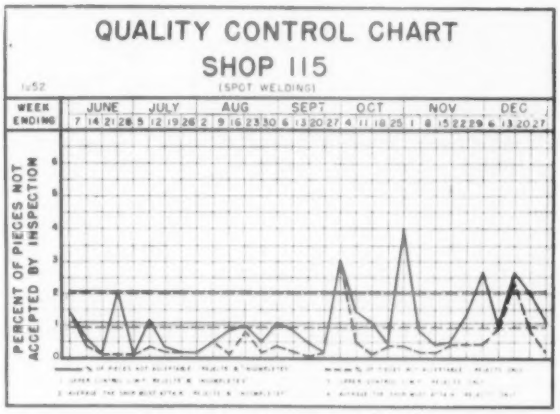

Fig. 1 Quality control chart

With modern 3-phase equipment the source voltage must be maintained within reasonable tolerances or there must be some means of current control provided within the spot-welding equipment to compensate for such variations. Similarly an adequate air supply system should be provided for the equipment.

At the time of initial certification, certain standards and calibrations are made for later reference during overhaul or in case of machine breakdown or replacement of major parts. The calibrations are accomplished by using oscilloscopes or oscillographic equipment, Fig. 2. Current traces are obtained in conven-

Fig. 2 Oscillographic equipment

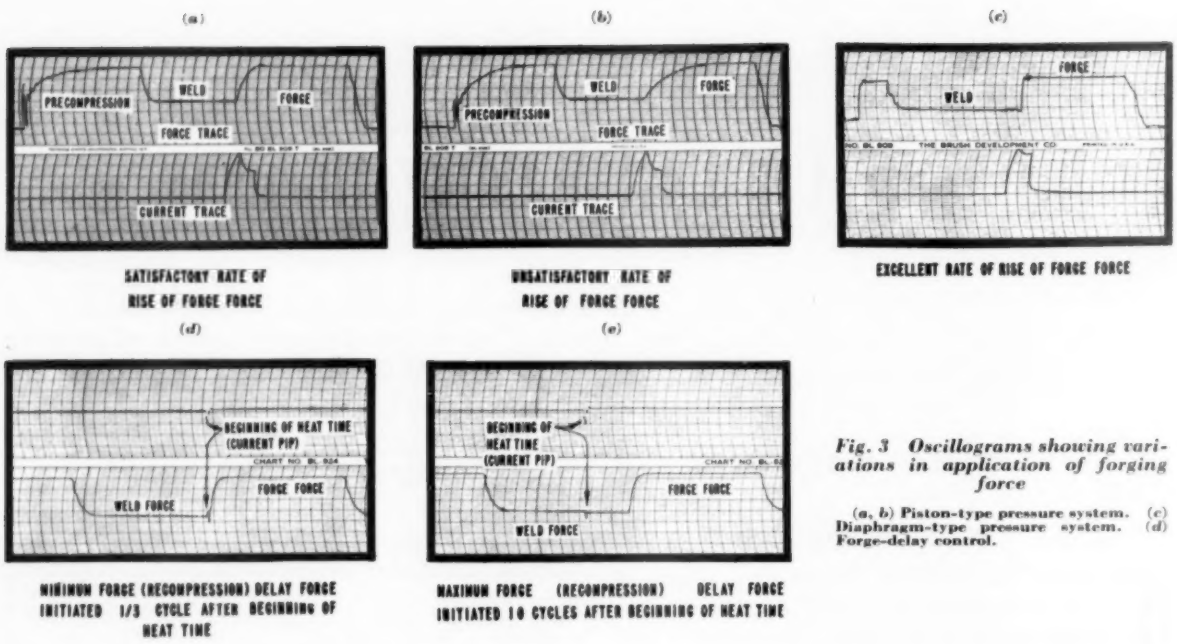

Fig. 3 Oscillograms showing variations in application of forging force

(*a*, *b*) Piston-type pressure system. (*c*) Diaphragm-type pressure system. (*d*) Forge-delay control.

tional manner using solenoid or toroid pickup coils in the secondary loop with an associated integrating amplifier or by measuring the voltage drop across a section of the secondary conductor of a known resistance. The pressure pickup is usually obtained by the use of strain gages mounted on the electrode holders, the support arms or on an auxiliary brace. Current force relationship must be closely controlled if welds of consistent quality are to be obtained continuously in production.

The spot-welding equipment should be checked out for proper sequencing and operation prior to running any consistency tests or developing any welding schedules. The various timers associated with current control are usually checked for calibration and the calibration established in standard units such as milliseconds or cycles. An oscillographic recording is usually made showing simultaneous traces of current and pressure values. From this oscillogram it can be determined whether or not the forge (recompression) delay timer has sufficient range of adjustment and is properly set so that the forge can be cut in at the necessary time to insure freedom from cracks. Similarly the slope or rate of rise of the forge application can be studied to determine any adjustments necessary to the various valves associated with the pressure system, Fig. 3. Occasionally it may be necessary to completely revise the pressure system in order to provide an adequate control. On frequency converter machines the firing circuit must be adjusted to provide uniform current amplitudes on alternate half cycles as shown in Fig. 4. In some instances resistance measurements are made of the secondary loop to establish an arbitrary standard to determine when maintenance is required such as cleaning of the secondary connections, arms, electrode holders, etc.

Electrodes must conform to some standardized design if complete control is to be realized. Design of these electrodes would necessarily specify the required face contour, the material, the depth and diameter of the water-coolant cavity and the length and diameter of the electrode. If more than one type contour or electrode material is being used in production it is desirable to code each electrode so that the operator may be able to identify the particular electrode being used as being the proper one for the developed welding schedule. Electrode wheels should be bought to definite specifications and the material received should be checked to be in conformation with these specifications. The very best quality control can be disrupted by the use of poor electrode material or poor wheels, particularly on long runs where soft electrodes or wheels tend to give a satisfactory indication at the start of the production run but may flatten or mushroom and produce poor quality welds before the end of the run.

It is also desirable to check out any associated equipment that is to be used in conjunction with the welding equipment itself such as automatic tables, feeds, etc. It has been noted that in production some weld failures have been observed, particularly on intermittent motion operation, due to the welding wheels and table motion continuing due to inertia, etc., so that welds were made while the material was in motion. The initial setting had been established for the weld being made when the wheels were fully stationary so the resulting welds were elongated and lacked penetration. In another instance the machine setup was correct and in accord with quality control requirements, yet subsequent failures developed in production which were caused by the plane of the electrode being below the normal plane level of the table so that the welds were

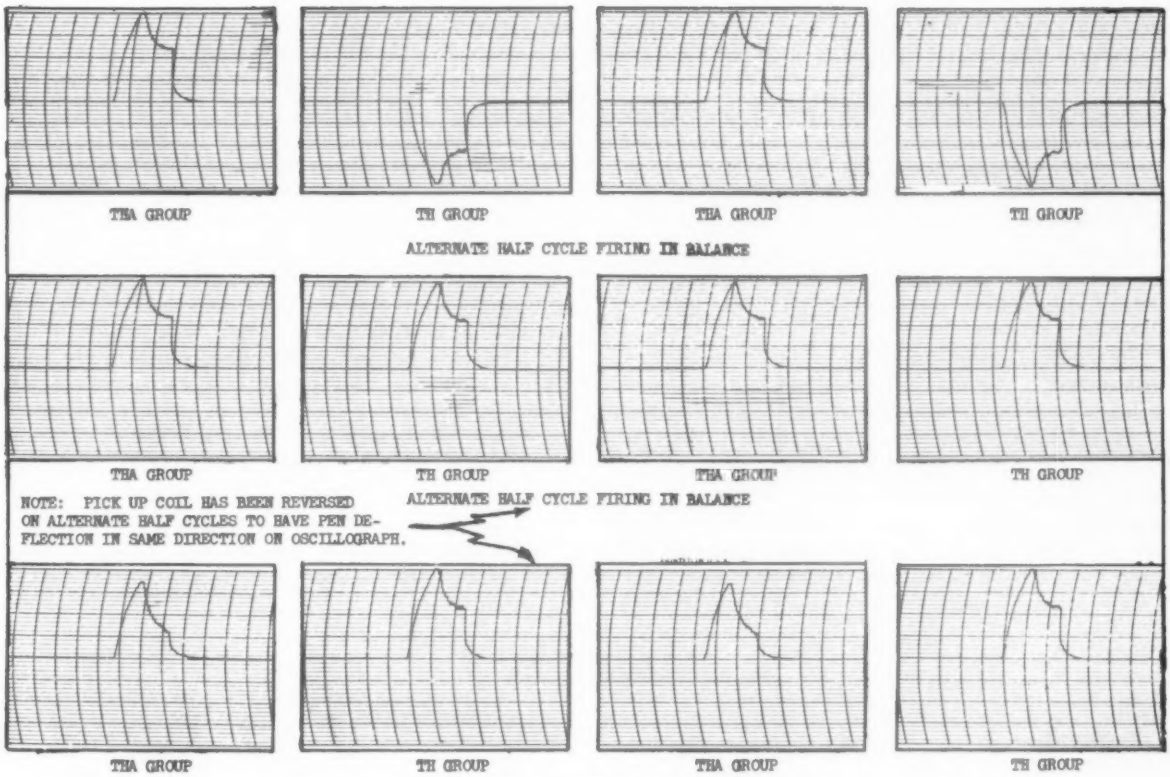

Fig. 4 Oscillogram of welding cycle showing alternate half-cycle unbalance and balance

made on sheet material that was more or less in a stressed condition giving excessive contact to the upper electrode and forcing the penetration out of the upper sheet. It is easy to see why normal quality control methods would not detect this sort of a failure until the finished product was checked. The preventive or control measures must be established in the method of setting up the equipment in its initial stages and passed on to the operators and set-up men who are using this equipment in production.

In calibrating or in checking out equipment during the maintenance operation, the testing equipment should be at least as accurate as the welding machine being tested if any degree of control is to be realized. To determine whether variations indicated by the oscillograms are due to the machine or the test equipment a calibrator, Fig. 5, was developed. This consists of a square wave generator with a regulated power supply in which an impulse can be induced directly into the pickup coil. Using this equipment the variations in oscillographic traces can be isolated as being a function of the welding equipment.

The application of the equipment is as follows: The amplifier gain setting is adjusted to give the desired deflection on the oscillograph on the initial welding schedule. The calibrator output is adjusted to give the same deflection on the oscillograph using the same amp-

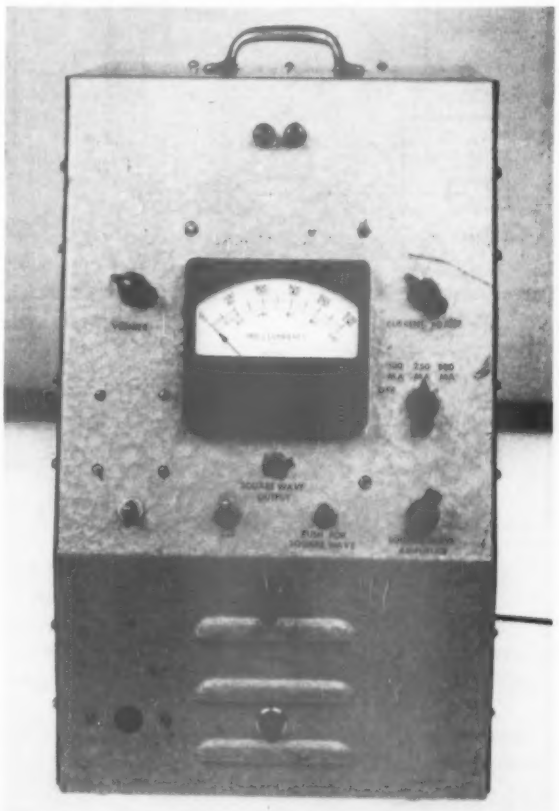

Fig. 5 Spot-weld test equipment calibrator

lifier gain setting with the pickup coil inserted in the calibrator. The exciter coil current is recorded for permanent use.

On a repeat test of the welding schedule, using the same machine setting, the current amplifier gain control is adjusted to duplicate the original deflection on the oscillograph, Fig. 6. The variation in pulse current in the calibrator coil required to produce the same amplitude deflection indicates directly the variations in the welding current. This sytem functions independently of variations in pickup coils, amplifiers and oscillographic elements.

The quality control system can be no better than its weakest link. The best resistance welding equipment in the world is no better in production than the routine or preventive maintenance schedule that has been established and is enforced. The routine equipment overhauls should be coordinated with the periodic oscillographic or consistency tests. A typical maintenance check sheet is shown in Fig. 7. Note that provision is made for the maintenance personnel to sign off the maintenance operation. If the oscillographic test indicates malfunctioning of the equipment it is possible to check back on the workmen responsible for the job. This maintenance is accomplished on an off shift basis (third shift) to avoid shutting down the machine during regular production (first and second shifts).

A monthly control test is shown in Fig. 8. This provides a spot check of two settings at the minimum and maximum gage schedules being used in production. The deviations required to duplicate the original strength and quality requirements and the oscillographic calibrations are checked. The maintenance department is allowed a deviation equivalent to half the normal limits of adjustment. For example normal limits of adjustment are $\pm 10\%$ in any one setting of current or pressure or $\pm 5\%$ in all settings. A special overhaul is made if the original test schedule cannot be duplicated by an adjustment in any one control of $\pm 5\%$ or in all controls by $\pm 2^1/_2\%$.

Why is a satisfactory maintenance control a vital part of the quality control system? A poor main-

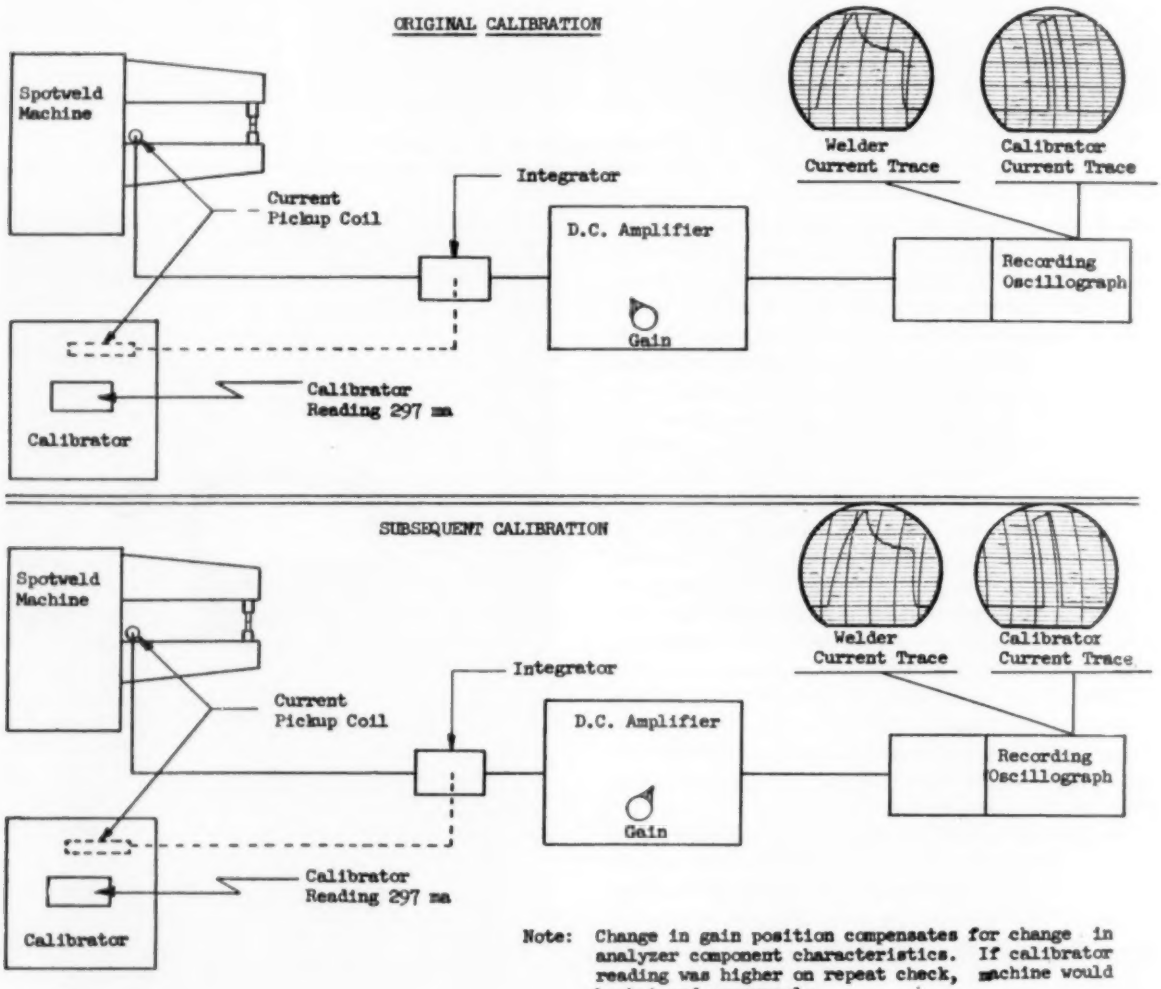

Fig. 6 Calibrator block diagram

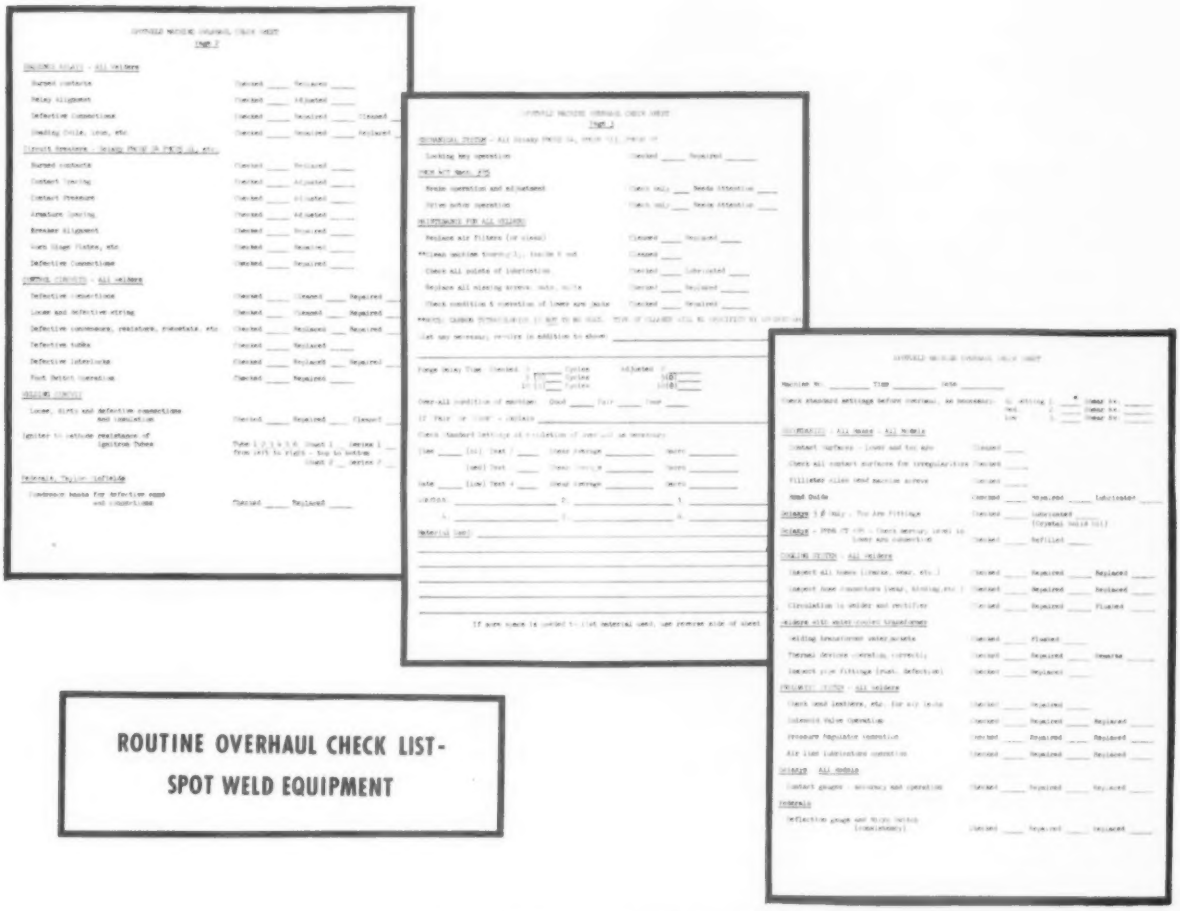

Fig. 7 Maintenance check sheet

tenance policy results in the machine operator's inability to repeat the consistency and quality requirements on production welding schedules within the specification limits of current and pressure adjustment.

Proper maintenance requires the isolation of the *real* cause of the trouble and the application of the correct remedy instead of juggling component parts to effect a temporary repair. For example—if the machine will not produce welds of adequate strength when the full maximum limit of allowable current adjustment is used, it may be possible to adjust circuit components to produce satisfactory results. This can happen on successive occasions over a comparatively long period of time until finally the limits of circuit adjustment or "jimmying" have been reached. The machine operation may then be analyzed and the real cause of the difficulty or the apparent "cooling off" may be isolated as a function of increased secondary circuit resistance due to oxidation of contact surfaces, or to build up of restrictions to coolant water flow in the transformer and conductors or both, faulty relay or tube operation or any of the other sources of this trouble and the proper remedy then applied.

The effect of this type of poor maintenance on a quality control system is disastrous—the welding schedules developed in the interim period are suddenly useless. The welding schedules fail to function within the allowable limits of adjustment, making it necessary to recertify those welding schedules that are outside the limits. A good maintenance schedule contributes to a good quality control.

THE CLEANING PROCESS

A good cleaning process removes objectionable soils and oxides from the surface of the material to produce a uniform surface resistance on the parts to be welded. The surface resistance must be uniform within the limits that will produce satisfactory welds on the established welding schedules. The surface resistance may or may not be below 50 microhms depending on the welding schedules developed.

One of the first problems in the quality control for the cleaning process is to establish the optimum limits of operation of the solution. To establish these limits tests are run to determine the effect of varying the con-

SPOTWELD CALIBRATION RECORD

Machine No. 61 Date: 8-21-54

Type Machine: Sciaky 3 Phase

QUALIFICATION SPECIFICATION		TEST NO.		100		104
COMBINATION	TOP SHEET	ALLOY NO.		24S(AL)		24S(AL)
		GAGE		.028		.102
		CONDITION		T		T
	BOT SHEET	ALLOY NO.		24S(AL)		24S(AL)
		GAGE		.032		.102
		CONDITION		T		T
ELECTRODE FACE				TOP	BOT	TOP	BOT
		MAT		RWMA	RWMA	RWMA	RWMA
		DIA		5/8	5/8	1"	1"
		RAD		4"	4"	10"	10"
MACHINE SETTINGS				CONT.	CAL.	CONT.	CAL.
C.D. MACHINES	GAGE DEPT. (WELD)						
	GAGE DEPT. (FORGE)						
	CHARGING VOLTAGE						
	CAPACITORS (MFD)						
	TRANSFORMER TAPS						
ELECTRO MAGNETIC MACHINES	GAGE PRESSURE						
	PRIMARY VOLTAGE						
	PRIMARY CURRENT						
THREE PHASE MACHINES	PRESSURE GAGE #1			1150	1150	5700	5700
	PRESSURE GAGE #2			4000	4000	20000	20000
	WELD PHASE SHIFT			48	48	88	88
	WELD PHASE SHIFT VERNIER			50	50	50	50
	CURRENT DECAY PHASE SHIFT			38	38	44	44
	WELD TIME			10	10	30	30
	CURRENT DECAY TIME			4	4	10	10
ARM SPACING				10 1/2		10 1/2	
THROAT DEPTH				5 3/4		5 3/4	
CALIBRATOR READINGS				1ST	2ND	1ST	2ND
		A		130	129	365	364
		B		130	130	365	365
		C		130	130	365	364
		AVG		130	130	365	364
SCALE USED				200		500	
SINGLE SPOT SHEAR STRENGTHS		1		320		2135	
		2		305		2185	
		3		320		2205	
		4		324		2125	
		5		300		2230	
		6		325		2165	
		7		315		2200	
		8		310		2185	
		9		321		2120	
		10		301		2135	
		Total		3161		21795	
		Cal Ave.		320		2179	
		Cert. Ave.		292		2116	

REMARKS:

Calibration Made by: James Gardner, Maintenance

Witnessed by: [illegible]

Fig. 8 Calibration record

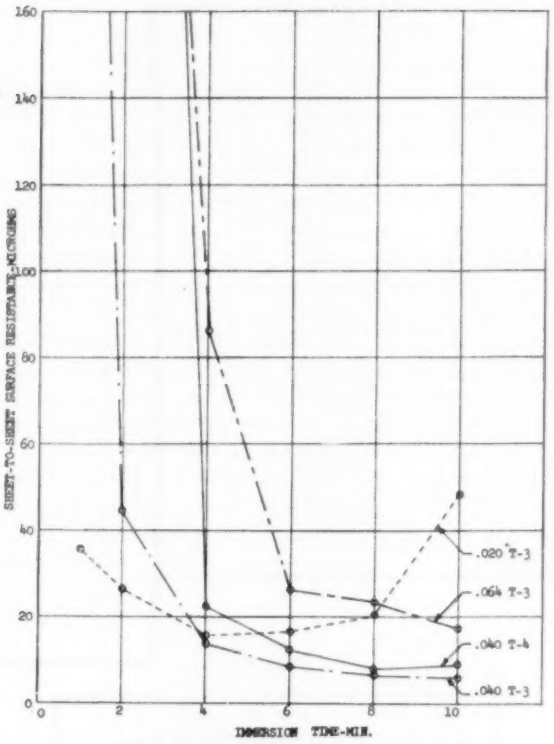

Fig. 10 Effect of immersion time for various gages

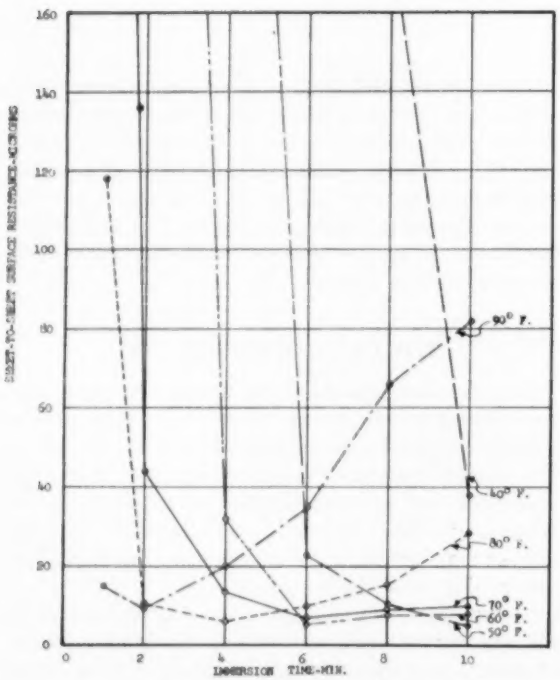

Fig. 9 Effect of solution temperature

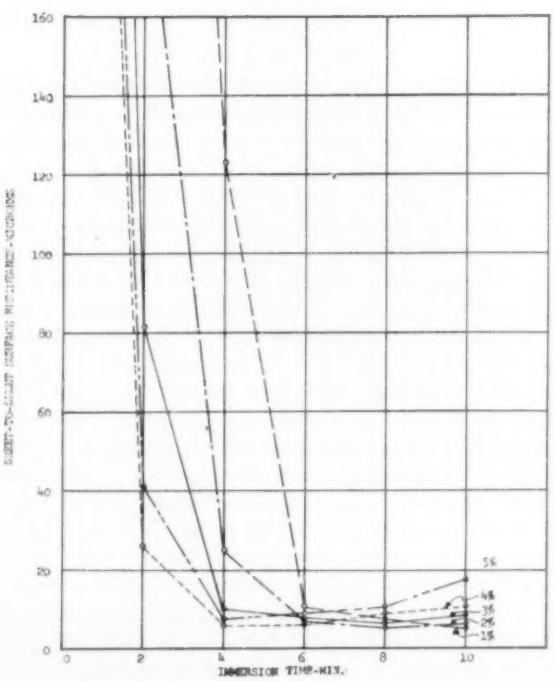

Fig. 11 Effect of solution concentration

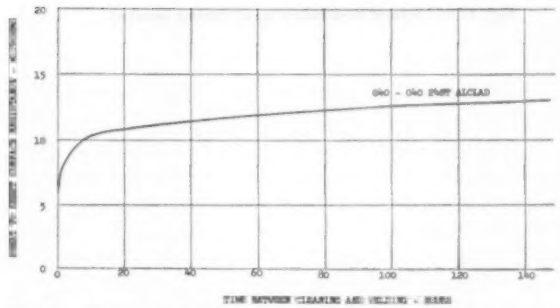

Fig. 12 Effect of time after cleaning on surface resistance

centration and temperature with various immersion times.

The effects of various solution temperatures for an $H_2S_1F_6$ solution are given in Fig. 9. The effects of varying the immersion times for different gages are given in Fig. 10. The effects of varying immersion time with various solution concentrations are given in Fig. 11. A similar procedure may be used to establish these limits for the alkaline cleaner. Because some deoxidizing solutions are critical to the temperature of the sheets being immersed, tests should be conducted to determine the effect by varying the temperature of the alkaline cleaner rinse water in order to establish the optimum operating temperature.

After establishing the optimum limits of operation for the cleaning solutions, it is necessary to determine the limits of delay that may be allowed before welding must be accomplished. The effects of delay between cleaning and welding on surface resistance are shown in Fig. 12 and on shear values in Fig. 13. Having solved the first problem of establishing the limits of operation for the cleaning process it is then necessary to establish a system to keep the operation within the limits prescribed. Obviously, the factors to be controlled are the concentration, the temperature and the immersion time.

The solution concentration is maintained by the addition of sufficient new material to maintain the required concentration. Samples of the solution are titrated at periodic intervals to determine the additions necessary to maintain an active alkalinity at a pH of not less than 8.0 in the preclean solution.

One method of notifying the Welding Department of the proper additions to be made to the cleaning solutions and insuring that these additions are made is shown in Fig. 14.

The temperature of the solution is thermostatically controlled. The control is checked by measuring the temperature of the solution each time a sample is drawn for titration. Required adjustments are made by the Maintenance Department to bring the solution temperature within the specified control limits.

Although the above controls usually suffice for a normal spot-welding operation there are other items that should be investigated and their effects determined in order to maintain an over-all control of the solutions when used in production. It is desirable to plot curves of the variation of the constituents in the solution throughout its life as the total additions build up to equal 100% of the amount used for the original solution. With a suitable indication of the nature of the change of the solution throughout its life, a specific analysis can be made as an index of the proper time to dump or to change the solution before it is indicated by parts failure or by the complete breakdown of the cleaning process.

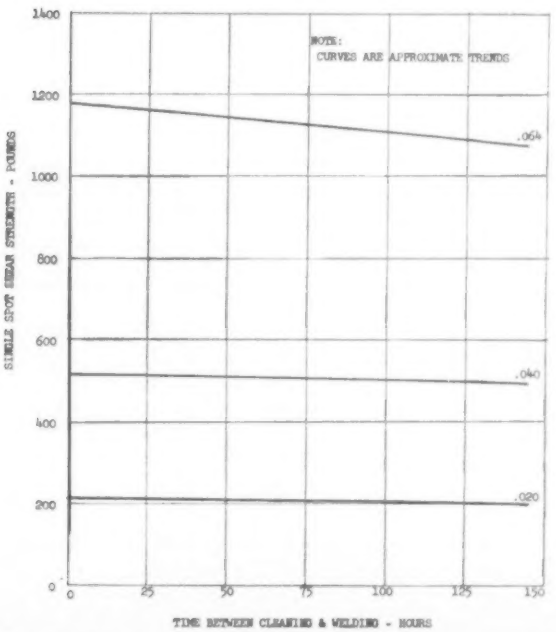

Fig. 13 Effect of time after cleaning on shear strength

SPOTWELDING SOLUTION

To: Shop 115, Fl. 2
Shop 710, Fl. 2
Feb. Insp., Fl. 2
AF Insp. DPC Bldg.

Date 2-2-52
Sample Dated 2-1-52

	STRENGTH	ADDITIONS
Turco 2623	5.48 oz/gal.	20 lbs.
Hydrofluosilicic Acid	41.2 gms/gal.	2 gal.

E. G. Karlsten
Chemical Laboratory

INSPECTION PROCESS CONTROL RECORD — Hydrofluosilicic acid Fl. 2 Spotweld

TESTS	REQUIRED RANGE	TEST FREQUENCY	1/16	1/18	1/21	1/23	1/25	1/28	1/30	2/1	2/4	2/8
Concentration	37.0-44.0	Daily	43	40.6	39.5	39.8	41.9	42.6	42.8	41.2	40.9	39.3
RECOMMENDED ADDITIONS:				2gals	2gals	2gals	none	none	none	1 gal	2gals	2gals
SHOP SIGNATURE			E.F	E.F	E.F	E.F	E.F	E.F	E.F	E.F	E.F	E.F
INSPE. SIGNATURE			J.D.	J.D.	J.D.	J.D.	J.D.	J.D.	J.D.	J.D.	J.D.	J.D.

Fig. 14 Cleaning solution control records

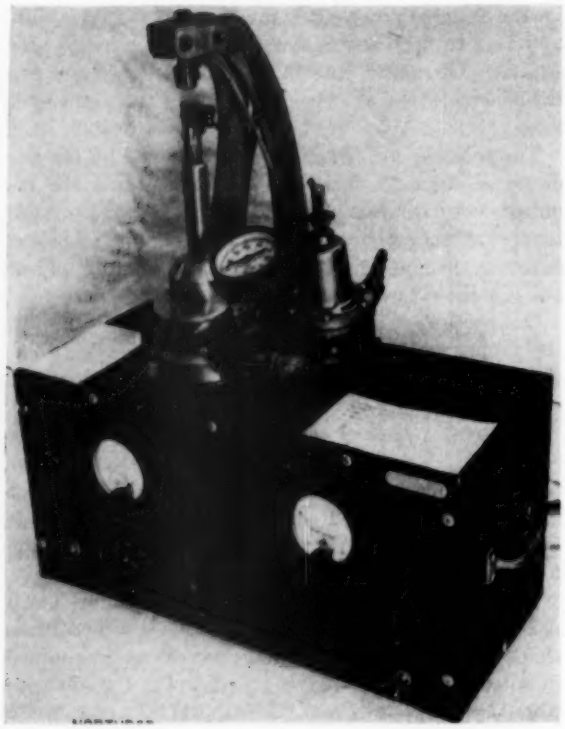

Fig. 15 Surface resistance measuring devices

It is desirable to establish an over-all control of the cleaning process. This is accomplished by measuring the surface resistance of parts or of test samples processed in the same manner as the production parts. Typical equipment is shown in Figs. 15 and 16. It consists of an apparatus which measures the voltage drop across the faying surfaces of two sheets of material held between electrodes under a given pressure, with a known current flowing through the sheets. To check the effect of the variables within the surface resistance measuring device, tests were run varying the current and pressure. Figure 17, and the tip radii Fig. 18. These indicate the stability of the instrument through a range of current and pressure values. For convenience, 4-in. radius tips, 1000 lb electrode force and 100 amp current were selected. By using 100 amp with conventional electronic voltmeters it was possible to interpret the voltage drop as a direct function of the surface resistance in microhms. The calibration of the equipment should be checked at periodic intervals.

The surface resistance measurements may be made at periodic intervals and plotted as shown in Fig. 19 to be used as a statistical control of the cleaning proc-

Figure 16

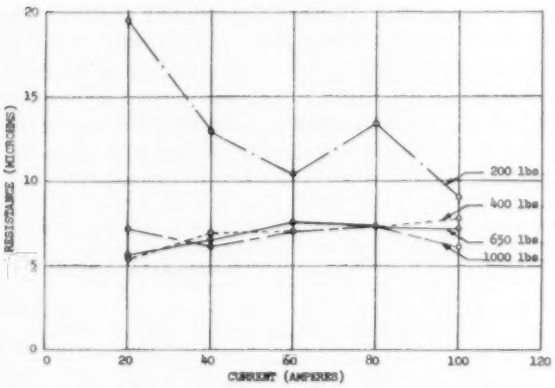

Fig. 17 Effect of current and pressure on surface-resistance measurements

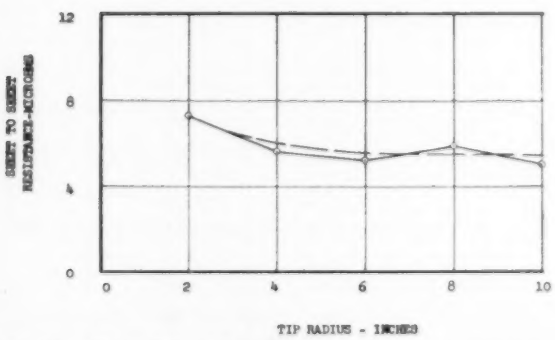

Fig. 18 Effect of tip radius on surface-resistance measurements

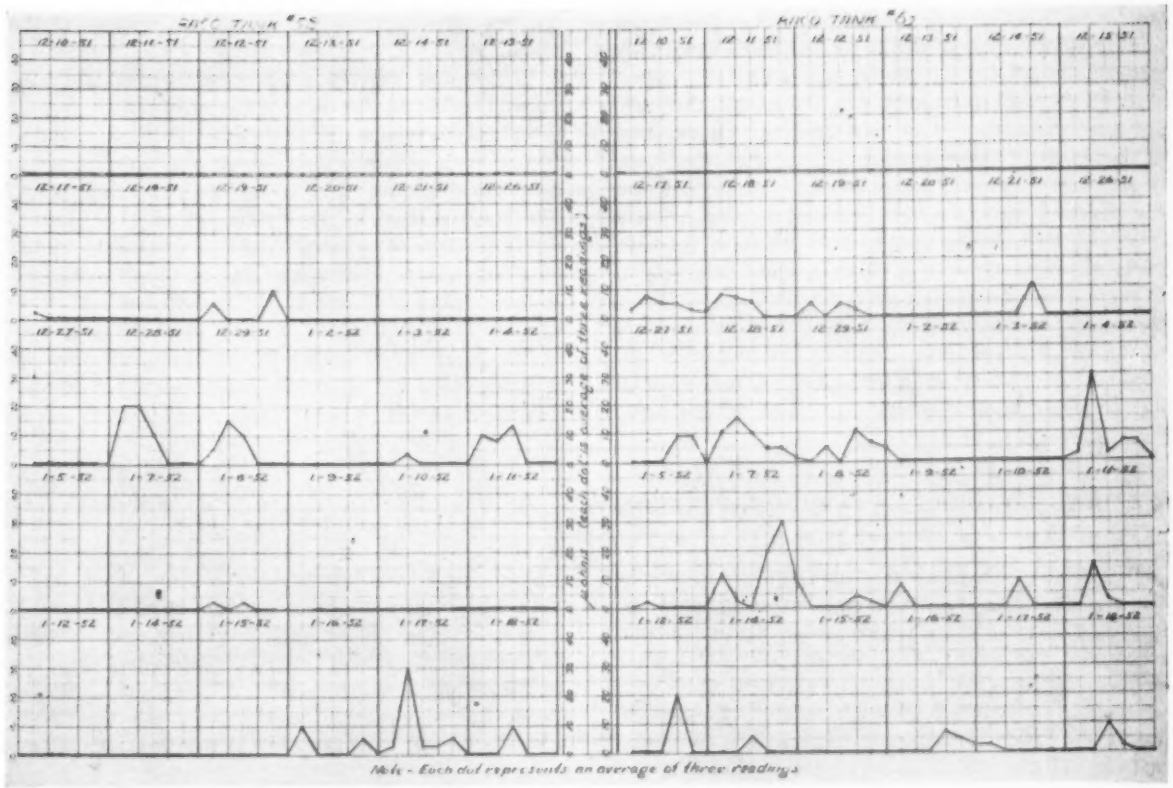

Fig. 19 Surface-resistance chart

ess. Surface-resistance measurements may also be used as shown in Fig. 20 to indicate the production performance and stability of the solution over a period of time.

Although no attempt has been made to correlate surface resistance with the weldability of the parts, the data obtained from the measurements have been very useful in the control of the cleaning process and in predicting and avoiding difficulties before the poorly cleaned parts reach the machines.

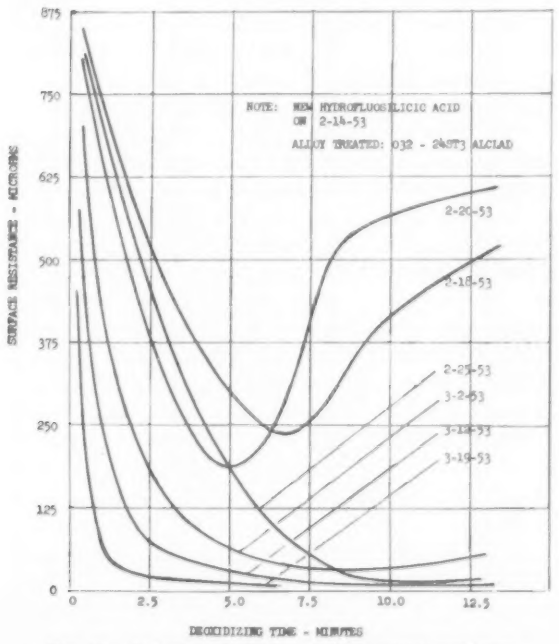

Fig. 20 Solution variations after initial makeup

PARTS AND MATERIAL

The allowable substitution of materials as called out on drawings can cause considerable consternation in the application of a quality control system unless the particular machine settings being used have been developed to be adaptable to the different types of material, the original callout and the alternate. Since spot welding is an assembly operation of individual parts, the accumulation of tolerances on individual parts may contribute to unsatisfactory welding conditions.

Unless carefully controlled in the make shops, the width of flat and the edge margin can be much too narrow to accomplish satisfactory welding. Variations in tolerances may also cause poor fit-up of parts making it impossible to weld the parts on the conventionally developed welding schedule. In a similar manner the progress of the parts through the various processes, such as lubrication of the stock for initial forming operations then failure to remove the forming oils prior to heat treatment, may be reflected in the failure of the cleaning process to remove the heat-treat scale even though the cleaning process was apparently under con-

trol for parts not requiring heat treatment. The proper quality control system would control parts eventually routed to spot welding from the time of their conception through the various stages of processing until the parts are ready for assembly by spot welding. Cooperation of the Quality Control Departments in the make shops is essential. There is probably little need to mention the effects of using conventionally developed welding schedules with flat-test strips and applying these to parts of severe contour or parts in which difficulty in fit-up is encountered. One solution to this problem is the use of welding schedules developed on actual parts or sections of actual parts. This method also takes into account the variations in resistance of the material due to plant heat treatment over that of mill heat-treated stock.

WELDING SCHEDULES AND PRODUCTION TESTS

The welding schedule is the heart of the quality control system. The production tests are an index of the functioning of the variables that make up the welding schedule. The quality and consistency of the spot welds in the parts can be no better than the welds that were made to establish the schedule and will only approach that standard in so far as there is a similarity between the test sample and the part and between the setups used to weld each of them.

To reduce the possibility of operator errors in machine setup the welding schedule is recorded on a form, Fig. 21, that simulates the location of the controls of the machine.

Four systems of weld schedule development and associated production tests or control are as follows:

In the first system (MIL-W-6860) the development of the welding schedule consists of spot welding a lap joint panel containing 25 welds in the same gages and alloys to be used in production. Twenty of the 25 welds are tested in shear. The average and minimum single-spot shear values must exceed the minimum allowable values given in Fig. 22. Ninety per cent of the sample welds must have a shear consistency within $\pm 12^1/_2\%$ of the average and the other 10% may be within $\pm 25\%$ for aluminum. The other 5 welds are examined for weld soundness and for penetration within the limits of 20 to 80% of the sheet thickness.

The routine quality control production test consists of a 3-spot-weld lap joint welded at hourly intervals, at the end of the run if less than 1 hr, at replacement of welding electrodes and each change in material or gages being welded. In addition a 3-spot-weld sample for macroscopic sectioning is welded at each change in materials or gages being welded. The average strength of the three specimens must be equal to or exceed the strengths given in the previous chart for the gages being welded and the variation between the lowest and the highest strength weld of the three cannot exceed 35% of the average.

The average individual shear strength and the range is often plotted as a means of statistical control for the given gage and alloy combination on a specific machine as shown in Fig. 23.

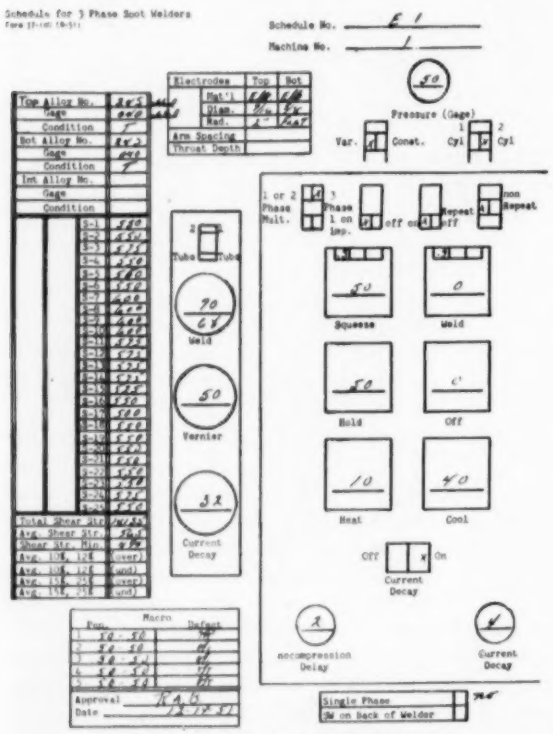

Fig. 21 Machine setup chart

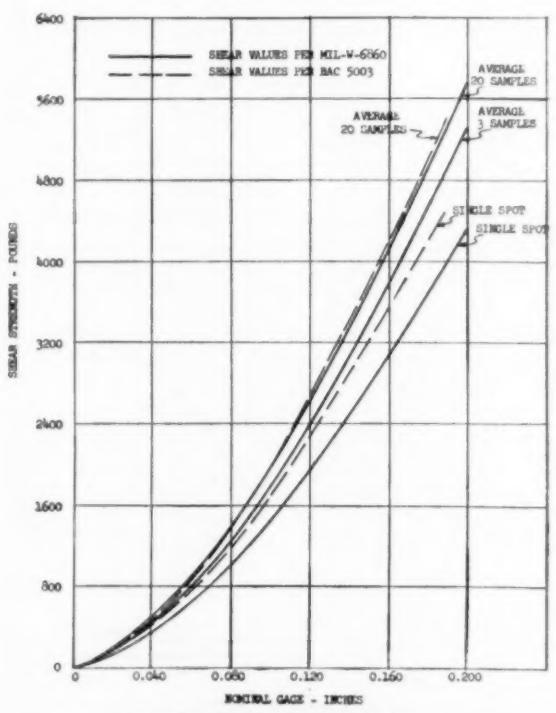

Fig. 22 Required shear values

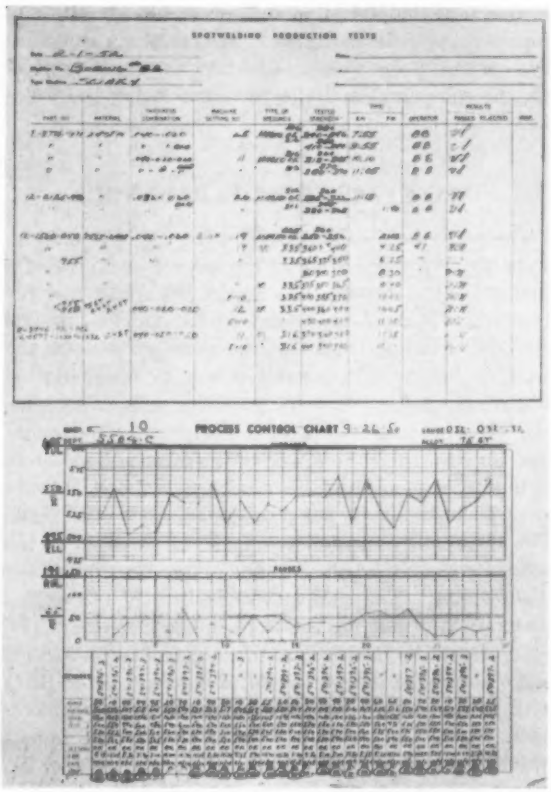

Fig. 23 Production test records

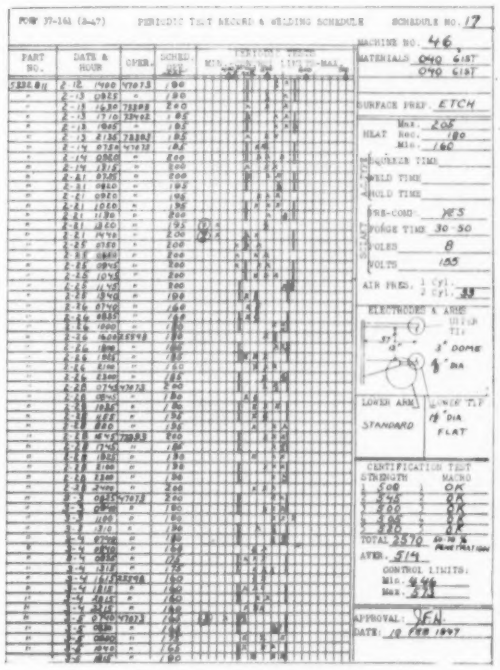

Fig. 24 Periodic test record

In the second system the development of the welding schedule consists of making 8 spot welds in the gage and alloy combinations to be welded in production. Three of the 8 welds are examined macroscopically with the penetration limits and allowable defects similar to system one. Five of the 8 welds are tested in shear. The minimum average shear must be equivalent to the requirements of System 1. The production control limits are established as $\pm 12^1/_2\%$ of this average for the gage and alloy being welded.

Three production shear tests are run at regular intervals, etc., the same as System 1 and are recorded on the periodic test record and welding schedule as shown in Fig. 24. After 20 consecutive sets of data have been recorded the data are statistically analyzed and/or the control limits refined if required.

In the third system of quality control the welding schedule is established by making 5 welds in a part or a simulated section of a part. These welds must be free of internal defects and the penetration held within the limits of 30–75% to 0.051-in. material and 20 to 80% above 0.051 in. The sample is checked for internal cracks by the use of a bend test as shown in Fig. 25.

Upon satisfactory completion of the metallurgical examination, a 20-spot panel is welded. These welds are tested in shear and the shear average is recorded as a part of the welding schedule.

Routine production shear test consisting of a 3-spot sample are run at 2-hr intervals and at each change in gages, alloys and on replacement of tips. The average shear value cannot be lower than 3% of that established at the time of certification for the same welding schedule.

In addition at each change in setup, change in alloys or gages and at intervals of 5000 welds, a 3-spot macrosection is made on a part or a simulated section of the part. The macro section must be within the acceptable limits of penetration and must be free of visual defects as well as passing the bend test.

System 4 is used for special-purpose spot welding of the most critical type.

The development of the welding schedule consists of

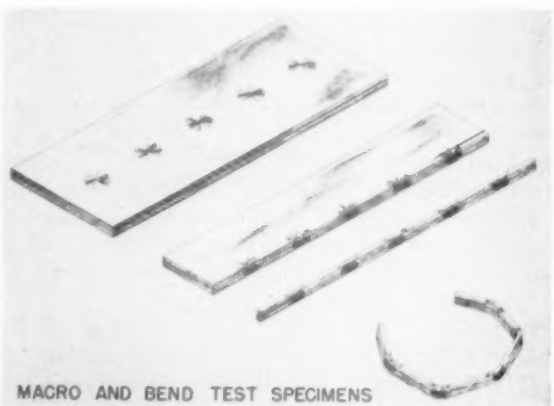

Fig. 25 Macro and bend test

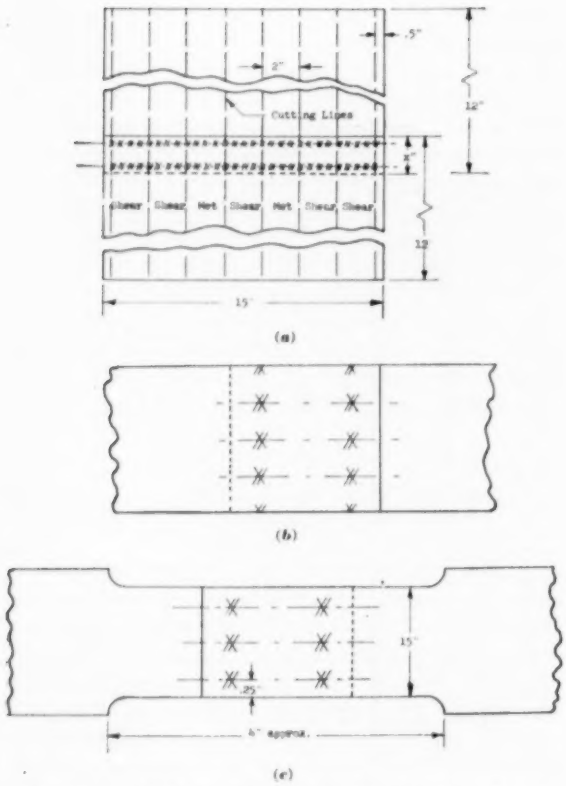

Fig. 26 Special-purpose test panel and test specimen

(a) Joint strength panel. *Note:* X-joint pattern and overlap varies with application and will be given on drawing. (b) Specimen for metallurgical examination. (c) Ultimate tensile strength specimen.

welding together two 12- x 15-in. panels using the same spot-weld pattern as the production joint, Fig. 26. If there is a hat-section stiffener and/or a doubler as an integral part of the joint it is included on the initial test panel. The panel is cut into seven 2-in. wide specimens. Two are checked metallurgically and must be free of defects as in System 3. The other 5 specimens are milled at the spot-welded joint into reduced area tensile specimens. The average joint strength as indicated by base metal failure must exceed 50,000 psi.

Upon satisfactory completion of the ultimate tensile strength test panel, a 20-spot shear test panel is welded, cut and tested to establish an average shear value index for production tests.

Production tests consist of a 3-spot macrosection on a simulated part at periodic intervals with metallurgical and bend test requirements as in System 3. A 3-spot shear specimen is also made at intervals as in System 3. The average shear in production cannot be lower than 3% below that established on the 20-spot certification test for the gage combination and application being welded.

In addition to the above tests, each machine is checked at quarterly intervals on each shift by running a 12- x 15-test panel of the minimum and maximum gages being used in production and testing it for conformance to the 50,000 psi minimum average ultimate tensile strength requirement. This test is a combination control of the welding schedule, the cleaning process, the equipment and the personnel doing the welding.

MANUFACTURING PERSONNEL

The personnel in the Spot-Welding Department can probably contribute more to the success or failure of a quality control system than any of the controls of the other individual phases. They are the ones who control the flow of the parts so that the clean parts reach the machine before objectionable oxides or accumulation of dirt can make spot welding on the parts unacceptable. It is not practical to police every individual operation because then there would be so many inspectors or quality control men that the Spot-Welding Department personnel could not possibly get their work done. The best quality control system can be defeated by the lack of cooperation on the part of the man operating the machine. The weld quality is directly affected by the method of holding the work in the machine. The parts should be held so that the electrodes travel in a plane normal to the work. Misalignment of the parts with respect to the electrodes can result in weld failures. It is the machine operator who determines whether or not the tip contour is correct or whether his cleaning of the electrodes has destroyed the contour. It is the machine operator who discovers any evidences of overheating and tip pickup due either to poor cleaning or to inadequate setup or inadequate cooling in the machine itself. It is the machine operator who first discovers the ability of the machine to produce acceptable welds for the routine production test. It is the person in charge of the cleaning process that knows the small variations that occur day by day in the cleaning solution, making it necessary to change the immersion times in accordance with the results of his measurement of surface resistance on test samples being processed through the solutions.

In some plants the responsibility for the development of welding schedules has been placed directly within the machine operators. This has the advantage of making the operator responsible for the machine setting which he ultimately uses in production. Machine operators seem to have a lot more respect for machine settings which they have developed and they will use every allowable adjustment to make these machine settings produce good welds in production. The more responsibility that is placed upon the machine operator for the quality of the welds in the finished products, the more he will be alerted to the individual variations that may affect the resultant weld quality and he will be more inclined to call these variations to the attention of his supervisor for correction.

Another assistance to the quality control system of benefit to personnel is a personnel training or educational program. It is desirable to acquaint the personnel in all departments (Factory, Inspection and

Fig. 27 Spot-weld manuals

Maintenance) concerned with the spot-welding operation, with the functions of the individual controls on the machines and how these controls affect the resultant weld. For this purpose classes have been set up using texts as indicated in Fig. 27. In many cases it has been found that the machine operators are well qualified as to weld quality requirements and the functions of the factors that affect them. However, it is also essential to train supervision in this same line of thought since so many times production supervision is much more aware of the lot quantities that must be handled than they are of the quality requirements of individual parts.

In order to unify the efforts to produce quality welding, Maintenance, Inspection and Production personnel are given the same training course at the same time, if possible. A good quality control system is accomplished by the cooperative efforts of all departments concerned with the process. Quality must be built-in.

PROCESS CONTROL

The requirements for process control are outlined in specifications as shown in Fig. 28 setting forth the procedures and materials to be used and the acceptable limits of operation. The responsibility for operation

Fig. 28 Process specifications

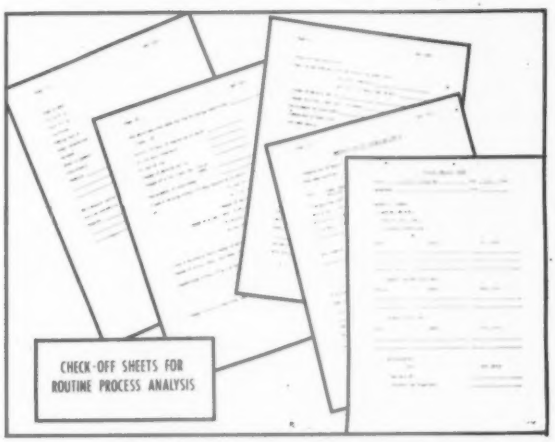

Fig. 29 Process analysis records

within these limits is cooperatively shared by Manufacturing, Inspection and Maintenance.

In some factories process control groups have been assigned to completely analyze the operation of the spot-welding process at periodic intervals. The check sheets shown in Fig. 29 are used in making such an analysis.

The analysis begins with the materials used in the spot-welding process. The sources and minimum stocks of cleaning compounds and electrode materials are checked. A change of source can sometimes introduce problems due to minor differences in material characteristics.

The cleaning process is analyzed and checked for chemical analysis frequency, temperature, concentration and the immersion times being used in production. The average daily additions of chemicals to the tanks is recorded to indicate any abnormal operation. The plotted surface resistance readings are checked for frequency and limits.

The welding technique is checked. The parts assem-

Fig. 30 Radiographic examination

bled for welding are checked for fit-up and for elapsed time after cleaning. The machine setting in use is compared with the certification schedule, including electrode contour, deviations in current or pressure settings, and macro, bend, shear and consistency tests. The clearance of electrodes on automatic tables is measured.

The periodic maintenance schedule is compared with the completion dates of routine maintenance for conformance. Static pressure calibration dates and drift are checked.

Typical parts are routed to radiographic inspection for a check of the weld quality, Fig. 30.

Upon completion of the analysis, a report of the findings is routed to the Manufacturing, Inspection and Maintenance Departments for the correction of any procedures that are not in conformance with process specification requirements.

The periodic process analysis is in effect a "preventive maintenance" schedule for the complete spot-welding process and if used at the proper intervals will overcome any trends toward laxity of control.

SUMMARY

Good quality control *is not* the application of a magic formula by the use of sampling methods to produce satisfactory parts from a poorly controlled process. Good quality control *is* the establishment of the satisfactory limits of operation for each phase of the process and the maintenance of operation within these limits. Quality must be "built-in."

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(*Continued from page 1159*)

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Fig. 1 Rio Blanco River bridge

Welded Arch Bridge Over the Rio Blanco River in Mexico

Erection of a 250-ft all-welded splayed arch bridge of unprecedented design over the Rio Blanco River near Vera-Cruz

by Thomas C. Kavanagh and Camilo Piccone

Abstract

This paper describes the erection of a 250-ft all-welded splayed arch bridge over the Rio Blanco River near Vera-Cruz in Mexico. Of unprecedented design, this structure has two outstanding features: first, a merging of the slender arch ribs to form a space structure eliminating a major part of the lateral bracing: and, second, a diagonal grid floor system of composite design, which has notable advantages with regard to economy and stiffness.

The bridge has already been acclaimed as an outstanding example of modern bridge architecture. It demonstrates that the same freedom of form formerly possessed only by concrete can now also be attained with steel as a result of our advanced knowledge and application of welding principles.

Thomas C. Kavanagh is Professor of Structural Engineering and Chairman, Dept. of Civil Engineering, New York University, New York, N. Y. Camilo Piccone is Civil Engineer and Contractor, Estructuras, S. de R. L., Mexico, D. F.

Presented at the AWS National Fall Meeting held in Cleveland, Ohio, Oct. 23, 1953.

DESIGN CONCEPTION

A STEEL arch highway bridge (Fig. 1) of entirely new design concept has recently been completed over the Rio Blanco River, 41 miles southwest of Vera-Cruz in Mexico. Since this is one of the first and largest all-welded arch bridges on this continent, whose design marks a decisive step toward a realization of a genuine welded bridge construction, this paper will attempt to describe some of the details of the erection of this unusual structure. The span of the bridge is 76 meters (approximately 250 ft), and it carries three lanes of traffic plus two sidewalks.

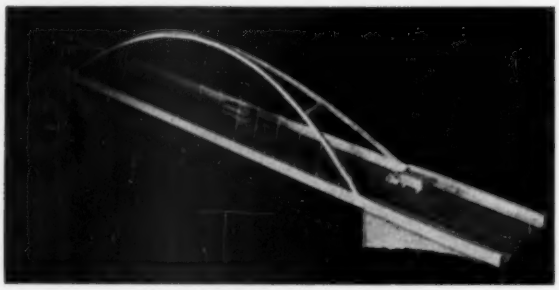

Fig. 2 Architectural model

The design of the Rio Blanco Bridge was prepared by Camilo Piccone of the firm Estructuras, S. de R. L., Mexican contractors, based upon a design by Dr. T. C. Kavanagh which received one of the major awards in the 1950 bridge design competition among professional engineers throughout the world, sponsored by the James F. Lincoln Arc Welding Foundation. It might be in order here to refer to a model photograph of the latter design (Fig. 2) in order to discuss briefly its pertinent features.

Structurally, the system (Fig. 2) is a pair of tied arches with slender ribs splaying at the crown to form a space structure with a minimum of overhead bracing. It is at once apparent from the model photographs that this bridge possesses an esthetic beauty inherent in a truly functional design, and a harmony of scale, material and detail not attained in other through-truss structures for the span in question. Economy is attained,

Fig. 3 Diagonal floor grid

Fig. 4 End view of bridge

(1) by the virtual elimination of top bracing without reduction in rigidity (since the ribs are arched in plan and brace themselves directly, without relying upon the interaction with a secondary bracing system); (2) by the reduction of effect of eccentric lane loadings; and (3) by the spatial interaction of the lower bracing system with the tie girder under vertical loadings, tending to reduce the axial load in the latter under eccentric lane loadings. The arch is self-anchored; it requires no massive abutments to take its thrusts, and thus is adapted to many locations for which ordinary two-hinged arches might not be suited.

An additional and important innovation of this design (not depicted on the model photograph) is the incorporation of a floor system of weld diagonal grid beams (but seen looking upward at the bridge in Fig. 3), which also serves as the lower bracing system, so that substantially the entire conventional upper and lower structural bracing is dispensed with, the lateral forces being withstood by the structure itself. Economies inherent in the arch and floor systems enable substantial weight reductions, amounting to as much as 30% of the steel tonnage and about 20% cost reduction in comparison with more conventional bridge designs.

The Rio Blanco Bridge design (Fig. 4) differs from that shown in the model photographs primarily in that it incorporates three lanes of loading (H-20) instead of two. The arch is parabolic and the vertical center rise is 52 ft 6 in. (16 meters).

The ribs (Fig. 5) are of box shape, comparable on a reduced scale to sections used on the St. Georges tied arch (except that they are welded) and very much similar in design to sections successfully employed on a welded Swedish railway arch bridge a few years ago.* The box rib is open on the under side, with batten plates connecting across at intervals of 3 ft center to center. The diagonal struts at the end of the box sec-

* Ingwall, Carl T., "Arc Welding in Steel Structures in Sweden," International Association for Bridge and Structural Engineering, Liège Congress Preliminary Publication, 1948, pp. 75–82.

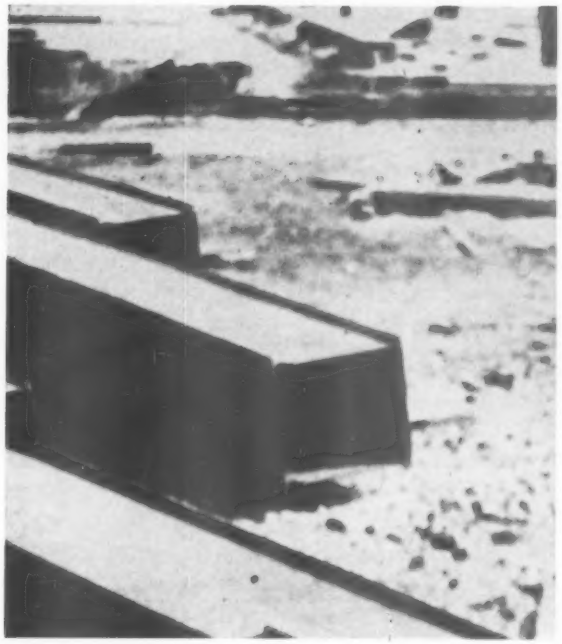

Fig. 5 Rib box sections

tion in the photograph are temporary erection braces at these points. The wire rope hangers (Fig. 6) are connected by adjustable closed bridge strand sockets and pins to two special vertical stiffener plates at each panel point of the rib. There are also two intermediate inside stiffening plates per panel length of rib.

The two ribs merge at the crown over a length of approximately 32 ft, and are also tied together by four additional horizontal box-shaped ties as shown in Fig. 7. A total of 15 wire rope hangers ($1^{3}/_{4}$-in. suspension bridge strands), manufactured by the Bethlehem Steel Co., are provided in each inclined arch, the panel spacing being 15 ft 7 in. (4.75 meters). The tie girder (Fig. 7) is inclined, lying in the plane of the ribs and hangers. The tie girder, which resists both tension and bending, has a 72- x $^{1}/_{2}$-in. inclined web, with horizontal flange plates varying in size from 18 x $1^{1}/_{4}$ in. to 18 x $1^{3}/_{4}$ in. Bottom hanger points (Fig. 7) consist of simple pairs of 8 x $^{1}/_{2}$-in. straps passing through the upper flange and welded to the girder web.

ERECTION OF BRIDGE

The erection sequence comprised the construction of abutments and simultaneous erection of falsework for floors; the fabrication of floor grid and girder sections, and erection and splicing of same; (9 splices per girder); raising of arch falsework followed by erection and splicing of arch segments (6 splices per rib); placing of lateral braces between arches; radiographic field testing of welds; placing and tensioning of cables; pouring of concrete floor; removal of falsework, and test loading.

The concrete abutments were of conventional type using cyclopean concrete, with tapered wing walls. Timber falsework bents, consisting of 6 x 14-in. stringers on 10 x 12-in. timber caps resting on 8 x 10-in. and 10 x 10-in. timber piles, were framed and erected by

Fig. 6 Rib Junction, showing hangers

Fig. 7 View of inclined arch plane

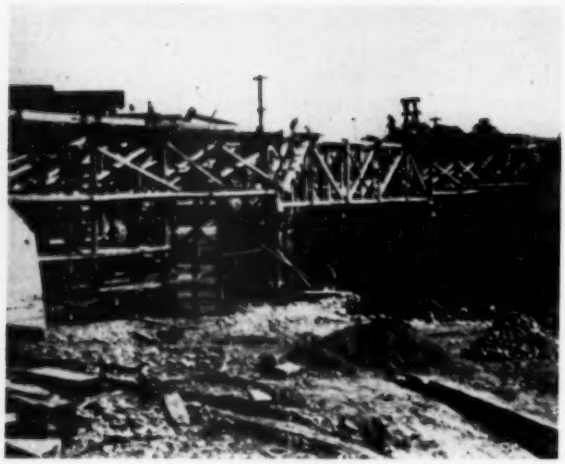

Fig. 8 Falsework

$^3/_4$-yd crawler crane and spaced 15 ft 7 in. (= panel length) along the length of the bridge except as noted later. The erection of the falsework was complicated by the unusual variety in levels of the Rio Blanco River, which has two annual rises around June and September. On July 1, 1952, due to a cyclone in the Gulf of Mexico, the river flow increased from a normal maximum of 230 cu meters per second (approximately 8100 cfs) to 850 cu meters per second or more (approximately 30,000 cfs), corresponding to a velocity of $5^1/_2$ meters per second (approximately 18 ft per second). This indicated that bents in the center of the river could not withstand such high currents and drifts. Four of the six temporary concrete cylinders that had been sunk (three on each side of the main central channel) as piers to support the long central section of the falsework, were undermined before sinking full depth and had to

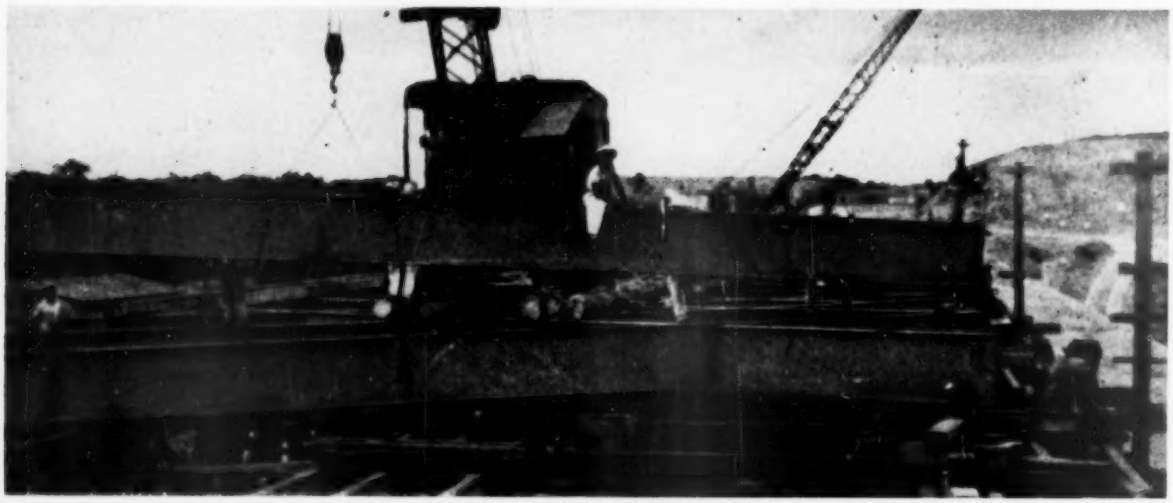

Fig. 9 Dovetailing of grid beams

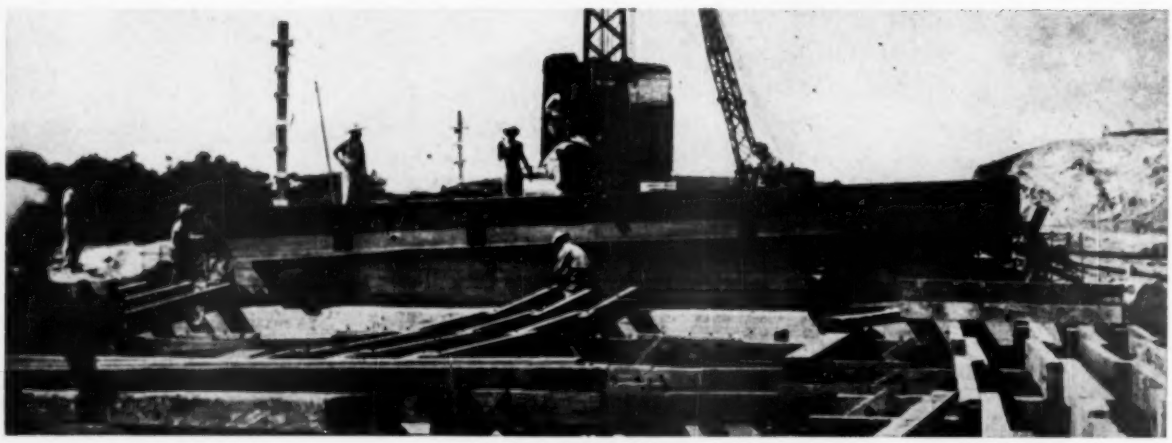

Fig. 10 End floor beam

Fig. 11 Tie girder section

be replaced by driven pile clusters to support eight timber 75-ft $5^1/_2$-in. (23 meters) trusses with split-ring connectors. These trusses were first framed and then erected by crane and tackle traveling on a suspension cable.

After the falsework was in place (Fig. 8) the floor grid and girders were assembled and welded. Floor grid beams are fabricated shapes (10x30 in. x55-ft $11^{11}/_{32}$ in. or 17.052 m), shipped from the fabricating shop at Monterrey where they were grooved by burning with a torch for dovetailing at the junction points. To offset the weakening caused by this notching special precautions were taken to reinforce these beams during shipment by welding two $^3/_4$-in. bars across the flange gap. The grid beams were stockpiled at one end of the bridge. The placing overlapping and welding of the grid beams is shown clearly in Fig. 9 which is a view taken along the centerline of the bridge. The panel geometry of this bridge was such that the grid beams (which connect with the girders at panel points) did not cross at right angles, but at a skew of 67° 36′. The placing of the first end floor beam (the only members transverse to the bridge) is shown in Fig. 10. These end floor beams are fabricated shapes.

Figure 11 shows the unloading at the railroad station "Paso del Toro" of a tie girder section with stiffeners, hanger points and grid connections prepared. Placement of such sections by crane is illustrated in Fig. 12. For temporary stringers for the crane, six palm trunks (8 to 10 in. in diam) were placed on the grid; palms are plentiful in the tropical zone.

Figure 13 is a shop photograph showing a section of the girder resting on a trial floor grid assemblage prior

Fig. 12 Placing tie girder section

to its attachment at the far left of the photograph. Girder stiffeners, sidewalk brackets, diagonal flange splices and grid stiffeners are clearly visible. It is of interest to note that the small triangular plates attached to the vertical stiffeners of the girder were put in to avoid transverse welding perpendicular to the direction

Fig. 13 Trial floor assembly in shop

Fig. 14 Welding girder splices

Fig. 15 Rib erection

of stresses in the girders. The stiffeners were not actually welded directly to the girder web, but only to these plates, and the plates to the web.

The welding of the girder to floor beams and of the girder splices is indicated on Fig. 14. The girder splices were butt welded, single U-grooved in the flanges, double V-grooved in the webs. The flange splices were made 45 deg transversely and staggered 1 ft on both sides of the web splice. Seven girder sections were fabricated in two-panel lengths, and one as a single-panel length, so that there were in all nine field splices in each girder. The splices were situated all at the centers of the panels, thus avoiding complication of details in hanger attachments at panel points and points of maximum bending moment.

The welding was carried out by three welders at the same time, one on each flange and another on the web; 4 to 8 hr work was required for each joint. No serious difficulties were encountered; the sequence of weld

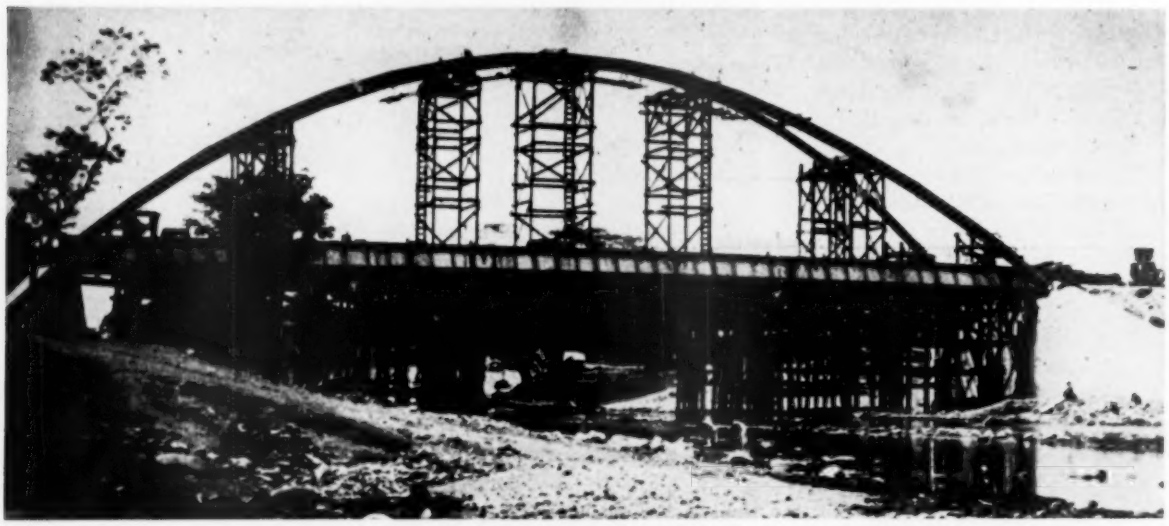

Fig. 16 Rib erection completed

deposition was similar to that described by Ingwall (see footnote, p. 1196) on a welded Swedish bridge.

Arch ribs were shipped to the site in sections two and three panels long, so that there were in all seven field splices to be made in each rib. The rib welds were at 90 deg to the length of the rib, and single-V grooved in both web and flanges. Welding was done by three welders simultaneously as in the tie girder welding.

Figures 15 and 16 show the progress of rib erection. During erection and welding the ribs were supported on seven timber towers and two cribs, corresponding to one support of each joint. Note that rib sections are actually straight segments, and that the welded joints were not situated at the theoretical panel points, but a little to one side to avoid complications in the interior diaphragms which support the hanger pins. Four temporary clips (Fig. 17) were welded on each end of the girder and rib sections to be fitted with field bolts for erection. The end juncture between rib and girder was shop welded.

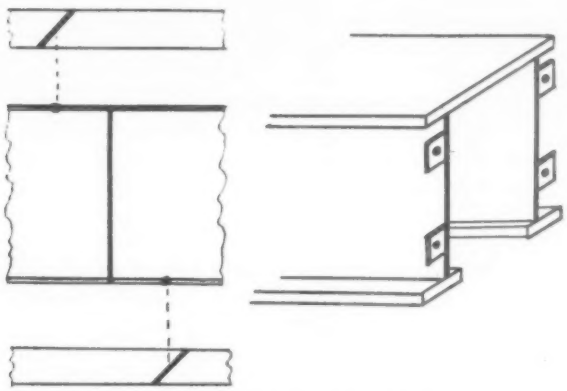

Fig. 17 Tie and rib splice details

Steel for the bridge was structural grade, low-carbon ASTM A-7-46, which tested 63,000 psi ultimate strength and 41,000 psi yield point. Field welds were by electric arc welding with Lincoln Co. coated electrodes (Fleetweld No. 7 sizes $^{3}/_{16}$ and $^{1}/_{4}$ in., and submerged automatic welding $^{5}/_{32}$-in. wire was used in the shop). Welding operators were all qualified for each welding position according to AWS test rules.

Considerable precaution was taken in view of the unusual nature of this structure, to undertake a careful program of radiographic (X-ray) weld examinations both in the field and shop. Examinations were done of all the girder field splices, rib field splices, and a limited number of grid welds and shop fillet web-to-flange welds at random. The Houston Gamma Ray Co. was in charge of the radiographic examination both in shop and field; they used special cells and photographic films, taking 17 sec per exposure. The only defects detected were small slag intrusions and light porosities, and in such cases the welds were chipped and rewelded. A few cracks were found at cross brace joints with the ribs on account of difficulties with uniform cooling. In order to secure some stress relief in field welds, all

Fig. 18 Stress relieving

field joints in ribs and tie girders were heated to approximately 1100° F using a 2-in. gasoline torch and asbestos sheet covering (Fig. 18). It was felt that this heating was a very important and advisable precaution for all thick field welds.

The hanger strand was erected and tightened by turning the socket nuts by hand and wrench. Special training was given the men in charge of tightening, by checking tension in the hangers by mechanical extensometers. In order to get a condition of no-bending dead load stresses in the girders, these were jacked before pouring the slab to a camber equal to a negative calculated dead load deflection; then the hangers were tightened to dead load tension and finally the whole structure left free of falsework. A permanent camber of $7^{1}/_{2}$ in. was provided in the tie girders.

Fig. 19 Floor slab

After radiographic testing of welds and jacking, the floor slab was poured (Fig. 19). This is an 18-cm thick (about $7^1/_2$-in.) concrete slab, with two-way reinforcing of $^5/_8$-in. bars. The slab concrete (28-day strength of 3000 psi) was bonded to the floor grid by $^1/_2$-in. diameter stirrup-type connectors, welded in pairs to the top flanges of the grid beams, forming under live loading a composite flooring of great strength.

Slab pouring was not done continuously throughout the bridge, but in sections two panels long and full width, symmetrically located with respect to the bridge center, so as to put the slab weight on the arch as uniformly as possible. Thus, labeling the panel points 0 to 16 from one end to the other, the pouring sequence was 5-7, 9-11, 1-3 13-15, 3-5, 11-13, 7-9, 0-1 and 15-16.

The structure was finally field tested by flooding the roadway (Fig. 20) to a depth of approximately 14 in. with water, providing a total load of 250 metric tons on the bridge, equivalent to H-20 loading plus concentration over three lanes. Strain gages in the center hangers were read during the pumping of test water, and deflections measured of the tie girders in the same points. Results were about 80% of the calculated figures, and are considered entirely satisfactory. Additional tests have been made to verify the action of the bridge with regard to live loadings. In general, the floor has proved much stiffer than was expected, probably on account of the composite action of the beam and slab system.

The slab was poured without any transverse expansion joint throughout the bridge. It was felt that if joints were left there would be very heavy stresses on the connectors adjacent to them.

The bridge construction was started on Feb. 10, 1952, and completed on May 7, 1953. It has already been described as one of the most modern styled bridges in the Mexican highway system. To achieve most favorable architectural effect, the bridge has been painted in orange color in the ribs and cherry red in the tie-girders to contrast with the surroundings. The final coat of paint is a plastic one expected to last longer than the common paints in the tropical zone.

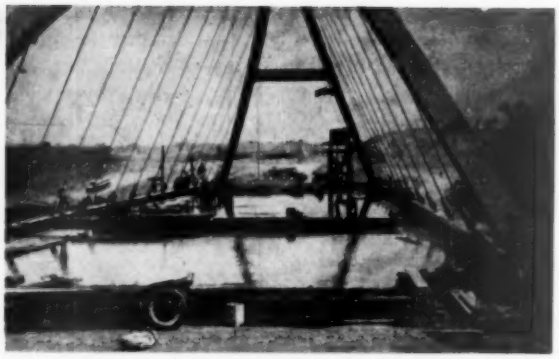

Fig. 20 Load test

ACKNOWLEDGMENT

The Rio Blanco Bridge was constructed as part of the Federal highway system of Mexico under the direction of the Papaloapan Commission (branch of the Secretaria de Recursos Hidráulicos). Acknowledgments are made to Arq. L-Gonzalez Aparicio and Eng. Raúl Sandoval, Executive Chairmen (successively); Eng. J. Ramos Magaña, Secretary Chairman; Eng. G. Oropeza and Eng. J. M. Herrera Chief Engineers (successively).

Contractors for the whole job, including design fabrication in their own shops at Monterrey, and erection of the steel structure, also of the construction of the the concrete abutments and falsework, were the firm of Estructuras, S. de R. L., whose managers are Eng. J. Fernando Guerra and Eng. Juvencio Gutierrez. Steel plates were milled by the Altos Hornos de Mexico S.A. shops at Monclova. Shop and field radiographic inspection of the welds was done by the Houston Gamma Ray Co. Strand for the hangers was produced and fabricated by the Bethlehem Steel Co. (J. B. Michael and N. S. Swanson, Mexican agents).

Finally acknowledgment is made to the Lincoln Arc Welding Foundation (particularly to A. F. Davis, C. G. Herbruck and E. E. Dreese) for their encouragement of welding applications which counted so much toward the realization of this project.

The senior author of this paper would like to take this opportunity to express his admiration for the courage, resourcefulness and skill with which Camilo Piccone carried out the design and construction of this structure, so much of which was without precedent. One cannot help but feel the same amazement which Arthur J. Boase imprinted on our minds some eight or nine years ago, after his survey of the structural accomplishments of our Latin-American neighbors, at the unusually high degree of professional integrity he found there.

Notice

Due to the Christmas Mailing Volume we have been cautioned not to send out our Buffalo Hotel Reservation Form just prior to then. Therefore they will be mailed immediately after Christmas. Processing and acknowledgment from Buffalo Hotels will commence Feb. 15, 1954 as previously scheduled.

the AMERICAN WELDING SOCIETY

activities • related events

Henry Neitzel Membership Awards

The AMERICAN WELDING Society with sincere pleasure announces the winners of the 1952–53 Henry Neitzel Membership Awards. Winner for the greatest net gain in number of registered members: Houston, Tex. Winner for the greatest net gain percentagewise of registered members: Pascagoula, Miss.

Greatest Net Gain in Number of Registered Members

	End of 1952	*End of 1953*	*Numbers Gained*
1. Houston	250	387	137
2. Los Angeles, Detroit	307 547	432 672	125 125
3. Pascagoula	37	92	55
4. Birmingham	64	108	44
5. New York	442	481	39

Greatest Net Gain in Percent of Registered Members

	End of 1952	*End of 1953*	*Gained, %*
1. Pascagoula	37	92	148.7
2. Birmingham	64	108	68.8
3. Houston	250	387	54.8
4. Los Angeles	307	432	40.7
5. Long Beach	86	120	39.5

AWS

End of 1952.....7937 Members
End of 1953.....9349 Members
Gain for year....1412 Members—17.8%

The SOCIETY is most appreciative to and congratulates the National Membership Chairman Ray L. Townsend, the National and Section Membership Committees and all Section Officers on an outstanding performance and record for the 1952–53 Membership Year.

A. F. Davis Welding Award

At the 34th annual meeting of the AMERICAN WELDING SOCIETY, held in Cleveland, Ohio, October 19th to 23rd, in conjunction with the National Metal Exposition, awards were presented for the A. F. Davis Undergraduate Welding Award Program. Roger C. Waugh and Otto P. Eberlein of Cornell University received the $200 First Award for their paper, "Penetration Factors in Metallic Arc Welding" which was published in the May 1953 issue of the *Cornell Engineer*. The $150 Second Award went to Wayne Jacobs and Charles Marshall of the University of Wisconsin for "A Comparison of the Quality of Weldments Prepared by Different Welding Processes," published in the *Wisconsin Engineer*.

These awards are made annually by the AMERICAN WELDING SOCIETY for the best papers on welding published in undergraduate magazines or papers. The publications receive cash awards equal to those presented to the authors. The *Cornell Engineer* and the *Wisconsin Engineer* received, respectively, $200 and $150. Miss Janice Button is editor of the *Cornell Engineer* and Robert Leisses in editor of the *Wisconsin Engineer*.

The purpose of the awards is to stimulate and encourage interest in welding among engineering undergraduates. The awards are named for their donor, A. F. Davis, Vice-President and Secretary of The Lincoln Electric Co.

Annual Report, Finance Committee (For Fiscal Year Ending Aug. 31, 1953)

The 1952–53 Fiscal Year was a most successful year. For the 12-month period ended Aug. 31, 1953, the SOCIETY experienced an excess of income over expenses in an amount of $22,234.92 as against $10,957.07 for the preceding year.

This result was accomplished by an increase in the SOCIETY's total income to $348,636.68, an increase over the prior year in an amount of $77,036.90 while corresponding expenses were increased in an amount of $65,758.05.

Income from Membership Dues increased by $16,260 over the preceding year. Income from this source before allocation of Dues Income to JOURNAL subscriptions amounted to $143,206, the registered membership having increased from 7937 to 9349. JOURNAL advertising revenue for the year was $86,828 as compared with $69,012 for the preceding year. Included in this year's revenue for the first time was income from the National Spring Meeting Activity in the amount of $32,279. However, the direct expenses attributable to this latter activity amounted to $30,409.

The comparison of budget against actual operations shows that actual revenue exceeded budgeted revenue by $62,786, this excess being accounted for principally by the above increases in Membership Dues, JOURNAL Advertising and Spring Meeting Activity. The principal sources of increases in budgeted expenses were JOURNAL advertising expense and the cost of

We sincerely appreciate the valued support, assistance and guidance of all AWS members and the welding and allied industry throughout the year, and extend our hearty wishes that you may enjoy a very

merry christmas
and a
happy new year

AWS NATIONAL AND SECTION OFFICERS AND AWS NATIONAL HEADQUARTERS STAFF

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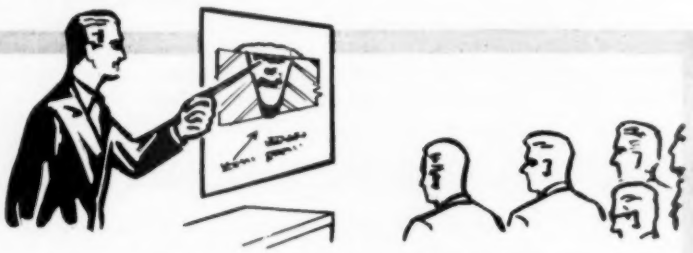

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the Spring Meeting. Actual expenses thus exceeded budgeted expenses by $41,118.

As a result of this year's activities, the operating funds of the SOCIETY as at Aug. 31, 1953, amounted to $59,528.62 as against $37,293.70 at the corresponding date in 1952; and the funds in the Reserve Funds Committee Accounts amounted to $122,144.98 as against $115,932.17 last year. Total combined Resources of the SOCIETY on Aug. 31, 1953, amounted to $181,956.17 as against $153,624.30 on Aug. 31, 1952.

At a meeting of the Finance Committee held in New York City on Aug. 27, 1953, the attending members discussed the matter of Headquarters housing. The office space presently occupied by National Headquarters is highly inadequate. After complete review and discussion members of the Finance Committee recommended to the Board of Directors for approval that a special account be established and that all funds to be placed in this account be earmarked for Headquarters Housing and further that 75% of the 1952–53 year's surplus be transferred to this account.

At a meeting of the Board of Directors held on Aug. 28, 1953, that body so approved of this recommendation as made by the Finance Committee. As a result of this action $16,676.19 of this year's $22,234.92 surplus will be transferred to a special account earmarked "Headquarters Housing" leaving a surplus of $5,558.73 in the SOCIETY's operating account.

Respectfully submitted,
R. S. Donald, Chairman
Finance Committee

Comments by National Secretary J. G. Magrath

As will be observed from our Treasurer's and Auditor's Report, our total income in the past year is up 28.2% over the previous year and total expenses increased 25.2%, in the same period; this results in a 6.75% excess income over expense for the past year, as against 4.25% for the previous period.

Income from THE WELDING JOURNAL, during the past year, accounted for 41.6% of the total income. Income from membership dues accounted for 41.1%. Other activities accounted for 17.3% of the total income.

While the membership numbers greatly increased by a gain of 1412 members, or a 17.8% increase over last year, the increase in membership dues amounted to but 12.8%. This results in only 41.6% of our 1952–53 year income, derived from membership dues, as against 48.7% for the previous year. Contributing greatly to this loss in ratio is the lack of sales in the Sustaining Member Classification. Unless a concerted effort is made to re-establish the proper balance between the regular membership and the sustaining membership numbers, the ratio will continue to

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decrease, the average cost of membership services will rise and we will be faced with increasing the dues for the "B" and "C" classifications. In 1947, Sustaining Members accounted for 1.75% of our membership numbers. As of the end of the past year, the ratio dropped to 1.24%. This is a red danger signal which the Secretary calls to the attention of the Officers and Board of Directors and all involved in Membership Promotion.

On the basis of 9349 total members, we should at this date, to have maintained the ratio, have a total of 188 Sustaining Members instead of 124. We need to increase this classification by 64 Sustaining Members, or 32% at once, in order to again reach the required ratio.

President's Annual Report

MEMBERS AND FRIENDS OF THE AMERICAN WELDING SOCIETY:

A year ago in Philadelphia, complying with the expressed wishes of our membership, I accepted the responsibilities of the Presidency of this great SOCIETY and pledged my diligent efforts in attempting to promote its best interests. This occasion marks the opening of our Thirty-Fourth Annual Meeting. At noon today the National Metal Exposition which we co-sponser, will open in the Cleveland Public Auditorium. It is appropriate that I should, at this time, bring you a brief report covering some of my activities and those of your SOCIETY during this year which has passed so quickly.

Due in large measure to the wise leadership of my predecessors—Jennings, Pierce, Fraser and many others; and in equally large measure to the effective performance of our very capable, loyal and hard-working staff—Magrath, Mooney, Spraragen, Rossi, Greenberg, Schramm, O'Leary and their associates who operate under the guidance of your Board of Directors; and perhaps in even greater measure to you—you who are members of our AMERICAN WELDING SOCIETY, you who are leaders and officers of our 62 active sections and of our seven districts, you who are members of our more than 100 operating, technical and special committees and juries of awards; and to the cumulative accomplishments which result from your individual activities; I can report that we have had a good year—one of steady, healthy growth, highlighted by the achievement of a few outstanding "firsts" and by the initiation of several activities which I hope and believe may result in further attainment of our primary aim: the advancement of the art and science of welding.

During the past year our membership has increased by almost 18% from a total of less than 8000 to one in excess of 9300, by far the largest number of members in the history of the SOCIETY. Following the fine records of Neitzel and Morrison, Ray Townsend has provided inspired guidance while creating continuing interest and activity with his "Membership Memos" and his personally created slogan "AWS Builds Men of Welding." Under his excellent leadership many of you working at the Section level have made possible by your personal efforts, this remarkable record. I am happy to announce that Ray Stitt of the Detroit Section has agreed to assume the leadership of this important activity for the coming year—in fact he is already organized and hard at work. Give him your full support and we can confidently look forward to a membership in excess of 10,000 when we meet in Chicago next year.

Because of our substantial increase in membership and a noteworthy increase in revenue from JOURNAL sales and advertising resulting from the effective work of Mr. Spraragen, and thanks to the careful control of expenditures by our exceptionally active and capable Treasurer, Mr. Donald, and perhaps even more to the effective management of our National Secretary, Joe Magrath, we have completed our fiscal year with a considerable cash balance. Most of this amount has been set aside by your Board of Directors in a special fund for headquarters housing. Anticipating an equally favorable income for the year ahead, your Board of Directors has authorized modest and long overdue upward adjustments in the salaries of our staff employees and have provided for slightly expanded activities of our Educational Committee.

During the past year it has been my happy privilege to participate in from one to three Section activities in each of the seven districts in which we group our 62 active Sections. During the past three years I have visited almost half of our Sections with two or more visits to several of them. I hardly need tell you—the men who plan and carry out the Section activities—what fine programs of technical meetings, educational courses, plant visits and social events most of our Sections conduct. This is the level on which we must and do serve most effectively. New Sections and Divisions of Sections have been formed during the past year. Each of you should study your own home region. Perhaps you can supply the initiative required to organize a small group of people vitally concerned with

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Really, you ought to try this torch . . . we promise you a pleasant experience.

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welding problems. With two or three really interested leaders such a small group can frequently be easily expanded into a Division or Section activity.

Under the general term "Technical Activities" we include the work of some 70 committees and subcommittees concerned with the preparation of codes, standards, and rules of practice on such diverse subjects as definitions and symbols, filler metals, safety, inspection, qualification, buildings, bridges, marine construction, storage tanks, pipe, automotive, ordinance and railroad welding. Mr. Greenberg has the herculean task of coordinating, expediting, refereeing, summarizing and finalizing the deliberations of the several hundred men who have developed and are developing these guides which make possible the orderly, economical development and expansion of the welding industry. Many of you participate in this most valuable activity. Each of you individually, if you are associated in any way with welding, has benefited from the work of these groups. Several standards have been completed and approved for release this year. We must find additional funds with which to provide assistance for Mr. Greenberg in speeding up and expanding these essential developments. At the meeting of your Board of Directors in Houston last June, the head of one of our major manufacturers of welding equipment presented a critical discussion of some of these activities. The ideas which he discussed are being carefully considered. Your Board of Directors has approved the formation of a special committee on Technical Services and Organization to study the needs of manufacturers and users, and to bring recommendations to the Board concerning the future scope and organization of these technical services. This committee will be headed by our incoming First Vice-President J. H. Humberstone. In this connection, note that we as a technical-engineering society cannot conduct many activities which are entirely appropriate for institutes and trade associations.

Members of your Public Relations Committee attempt to keep themselves informed concerning proposed legislation which might be ill advised or inimical to the best interest of the welding industry. This year with C. I. MacGuffie as chairman, they have given prompt and successful attention to such situations in California, Maine and New York. Each of you can help by calling to the attention of this group any proposed legislation on state or local levels which you feel they should investigate. H. F. Reinhard will head this activity during the coming year.

Our Educational Committee under the direction of J. Heuschkel has planned a broad and comprehensive program which has been seriously curtailed because of lack of funds. A small appropriation for the work of this committee has been included in the budget for next year. It is most important that some means be developed whereby Industry can adequately finance this program which would seem to be essential if Industry is to protect its own future. The program must cover every phase of activity in high schools, trade and vocational schools, and in colleges.

During the past year your Board of Directors has introduced a number of changes which add to the efficiency of operation of your Society. Your Executive Committee has met prior to Board meetings and has prescreened agenda items so as to insure careful deliberation and yet expedite action at the Board meeting. Your Year Book is now being arranged and published in departmental sections which can be more readily kept up to date. A new Industry Advisory Committee has been authorized and is being organized.

Your Constitution and By-Laws Committee has prepared a complete review and revision of our by-laws bringing them in line with current needs and practices, and including a number of suggested major changes. These will be submitted for your consideration during the coming months. H. O. Hill and his committee members have devoted much time to this difficult task. We are indeed deeply indebted to them. I believe the results

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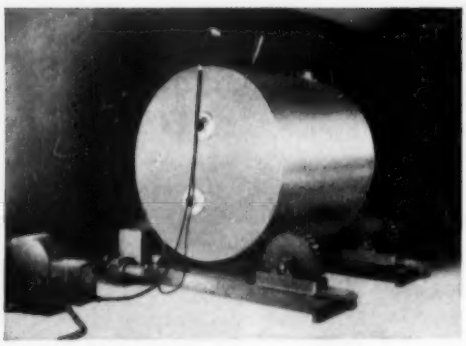

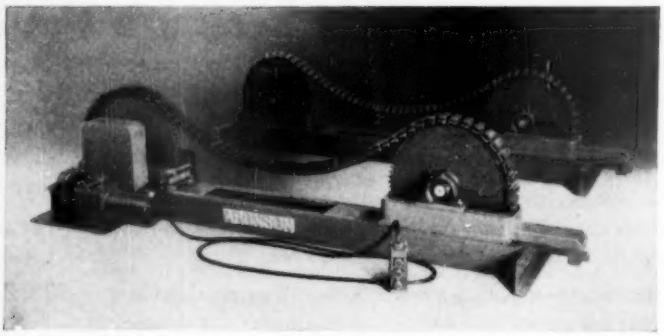

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No welding on ground lugs; No tangled ground cable. Positive, trouble-free grounding even when work is scaly and dirty.

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Jetweld is a shielded-arc type electrode designed for fast, easy operation with AC or DC. Powdered metal in the coating makes welds amazingly crack resistant, provides extra impact properties not found in conventional E-6012 electrodes. Welds compare in appearance with "hidden-arc" welds.

Operators like Jetweld for its smooth, stable arc action . . . its remarkable improvement in resistance to arc blow. Spatter is practically nil . . . welds are self-cleaning. Bead shape is flat.

Jetweld is designed for horizontal and flat position fillets, horizontal and flat position laps, single and multiple pass butts. It meets the physical requirements of a class E-7016 electrode and is used on work formerly calling for E-6012 and E-6020 electrodes.

JETWELD cuts deep into the 86¢ out of every welding dollar that goes for labor and overhead . . . can save you $14,190 per carload. Here's why:

FASTER WELDING—Jetweld's higher deposition rate now makes it possible for you to save enough money to warrant scrapping existing supplies of conventional E-6012 electrodes. Easier to restrike when cold, Jetweld simplifies tack welding. Simple to operate . . . Jetweld is a "drag" electrode with exceptionally stable arc characteristics.

HIGHER QUALITY—Weld metal is uniform, of X-ray quality, free of undercut with improved impact values at low temperatures. Jetweld is ideally suited for welding higher-carbon steels normally welded with low-hydrogen electrodes . . . without cracking and without surface holes There is no coating breakdown . . . stub losses are less.

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of their work may stand for many years as a monument to the care and thought they have given to each item.

Last February the AMERICAN WELDING SOCIETY suffered a sudden and serious setback in the death of our First Vice-President just two days after he had attended meetings of your Executive Committee and Board of Directors in Baltimore. Eric Seabloom had served our SOCIETY faithfully and well—many of you have met him and heard him speak at section meetings. I believe he would have established an outstanding record if he had been permitted to serve as President. We have missed his wise counsel and freely given assistance these past few months and will continue to do so. I am sure you all join me in wanting to express this brief tribute to Eric Seabloom. A more adequate resolution has been prepared and approved by your Board of Directors.

Later we were again saddened by the death of Past-President George Sieger, who for many years gave unstintedly of his time and energy to the advancement of our SOCIETY, and the Welding Industry.

This year for the first time we will hear an "Adams Lecture" presented by a representative of another nation—in this case our great and good friend across the Atlantic, Great Britain. Later this morning and at the Annual Dinner Thursday night our various awards will be presented. A new committee has been authorized by your Board of Directors and is being organized with Malcolm Priest as chairman, to make a thorough study of our awards program and to bring to the Board recommendations for a program which will better stimulate interest in advancement of the art and science of welding.

Last March our Los Angeles and Long Beach Sections, with H. K. Clemens as leader, prepared an excellent series of technical programs and co-sponsored the Western Metal Exposition held in Los Angeles. I was able to attend and can report that both the meetings and the exposition were unqualified successes. During June the First National Spring Meeting with Welding and Allied Industries Exposition of the AMERICAN WELDING SOCIETY was held in Houston. This event marked a significant change in your SOCIETY policies—one which has been considered for many years. It was an outstanding success. Today we open our thirty-fourth Annual Meeting, bringing to a close our 1952–53 administrative year. Next May the Second AWS National Spring Meeting and 1954 Welding and Allied Industries Exposition will he held in Buffalo. Next October our thirty-fifth Annual Meeting will be held in Chicago in conjunction with the National Metal Exposition. I am pleased to report that we have through friendly and cooperative discussions with the

management of the National Metal Exposition concluded a satisfactory agreement covering the holding of our independent expositions. Dr. Boardman who has been chairman of both our National Program Committee and National Papers Committee deserves great credit for the success of the Houston meeting and for this meeting in Cleveland which will, I am sure, be equally successful. C. I. MacGuffie and H. E. Rockefeller headed our 1953 Exposition Committee with R. T. Kenworthy as Exposition Manager. To these and the many men in Houston, in Cleveland and elsewhere who have made possible these meetings we give our grateful thanks.

There is in Europe an active organization known as the International Institute of Welding. Your SOCIETY has been a member for several years. One of our representatives, Howard Biers, is American Vice-President of the Institute. During the summer a group of engineers representing the Institute and selected from most of the European nations, came to this country under the sponsorship of the Mutual Security Agency. They visited educational institutions, laboratories and industries, and attended our Houston meeting. The AWS assisted in planning their itineraries and was host on several occasions. I have received many favorable reports from these men concerning their visit. Our Mr. Spraragen attended a meeting of IIW in Copenhagen, Denmark, during the summer (without expense to the SOCIETY). I am informed that Mr. Biers will probably become President of the Institute at a meeting to be held in Florence, Italy, next May. It is possible that a group of our engineers may be able to visit Europe and be present on this occasion.

These are a few of your SOCIETY'S activities for the past year. I believe you will agree that it has been a busy one and thanks to your efforts and those of our staff and our Board of Directors a generally successful one. We have a vital, living SOCIETY. It has been a pleasure, even though at times arduous, to serve with our able staff and fine group of leaders.

Now, confirming the recommendation of our Nominating Committee, you have asked me to serve as your President for a second term. I deeply appreciate this indication of your continued confidence. I accept again with a feeling of humility and a full realization of how little my own efforts have contributed to our record for last year. I do so because I know I can rely on your continued fine support. It has been said "History is never made in the abstract. Always it is something someone has done. History is never a solid mass achievement; it is a mosaic of countless parts, each one perfected by the sacrificial devotion of some particular person. The forces that have made history, and which

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will continue to make it, are the undying ideals men cherish, the strong-willed plans they discipline themselves to achieve, and the daring hopes by which they activate their souls."

We face many difficult problems. They must be solved if our SOCIETY is to assume its complete and broad responsibilities of leadership in promoting the science and the art of welding. We will need the help of men with broad vision, steadfast purpose, keen knowledge, unlimited patience, great courage, and unwavering faith. If you will help, we can face our future with complete confidence.

AWS

National Spring Meeting

Hotel Statler
Buffalo

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In connection with 1954
Welding and Allied
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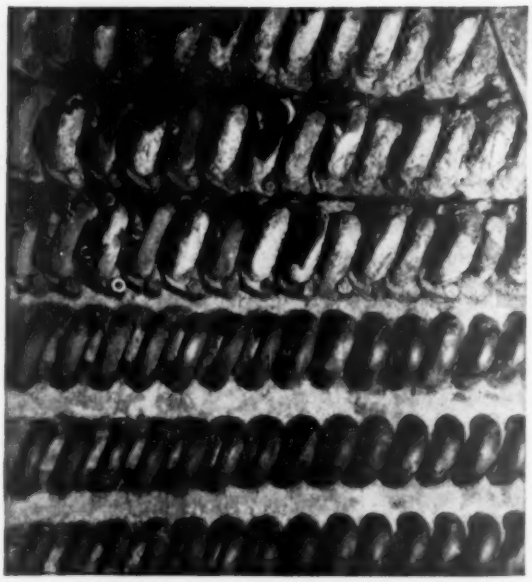

At top: flanged connections in economizer. *At bottom:* permanently leakproof, TUBE-TURN Welding Returns.

Shop fabrication of welded piping assemblies is easy, thanks to the uniform wall thickness and dimensional accuracy of TUBE-TURN Welding Fittings. Line-up is fast and accurate.

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Tube Turns, Inc. has prepared a booklet fully describing the production and specifications of pipe and fittings made from carbon steels and wrought iron; stainless steels; nickel and nickel alloys; [illegible]

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NEW LITERATURE

Steels for Low Temperature

Bibliography on Low-Temperature Characteristics of Steels, 1904—June 1953, with Author Index—Bulletin A-157, 48 pages. A much needed reference booklet prepared for Metals Division Special Libraries Assn. Lists, chronologically, 468 U. S. and foreign magazine articles, translations, pamphlets and books on the subject. An alphabetical Author Index increases its usefulness. International Nickel Co., New York 5, N. Y.

NBFU Pamphlet No. 51

The National Board of Fire Underwriters a few weeks ago issued the August 1953 revision of their Pamphlet No. 51, "Standards for the Installation and Operation of Gas Systems for Welding and Cutting." This new issue incorporates all recent changes suggested by the International Acetylene Assn. Copies may be secured from NBFU offices at 85 John St., New York 38, N. Y.; 222 W. Adams St., Chicago 6, Ill.; 465 California St., San Francisco 4, Calif. There is no charge for single copies.

Brazing Alloys

The United Wire and Supply Corp. of Providence, R. I., has issued two technical pamphlets. One of them is entitled "The Modern Way to Join Metals" and gives technical information on other various brazing alloys. The other is entitled "If You Braze the Coppers—Phoson Is Your Alloy." Both are available upon request.

Fillerare Welding

Three new bulletins on the recently developed Fillerare (registered trademark of the General Electric Co.) consumable-electrode gas-shielded welding process have been announced as available from the General Electric Co., Schenectady 5, N. Y.

An 8-page publication, designated GER-819, is a reprint of a paper presented before the AMERICAN WELDING SOCIETY by R. W. Tuthill of the G-E Welding Department. It contains information on the developments and experiments undertaken in the design and manufacture of the equipment.

Another 8-page bulletin, GEA-6028, contains description and application information and design features of the new welder. Profusely illustrated, it emphasizes the how-to-use-it aspects of the apparatus.

The third booklet, GEC-989, provides descriptive data on the Fillerare equipment as well as operating information, specifications and dimensions. It is four pages long.

Constant Voltage Welding

Answers to 14 basic questions regarding Constant Voltage power sources for automatic welding are given in a series of four data sheets published by the Glenn Co.

The theory of Constant Voltage welding, how it differs from previous its features, applications to inert gas and submerged arc processes are covered.

Copies of the data sheets may be obtained by writing the Glenn Co., 3134 E. 10th St., Oakland, Calif.

Quality Control Through Radiography

Industrial X-Ray, Inc., of West Hempstead, N. Y., a nondestructive testing laboratory, has just published a brochure, *Quality Control Through Radiography*, which is available, at no charge, to all interested persons in the aircraft, metallurgical, electrical and plastics industries.

Profusely illustrated with actual "case-history" photos demonstrating the applications of radiographic testing, it is designed as a primer for all those not yet familiar with radiography as a nondestructive testing tool, as well as a "capsule" review for those who are already using radiography in quality control work.

A copy may be had by writing to Industrial X-Ray, Inc., 220 Hempstead Turnpike, West Hempstead, N. Y.

Hard Facing

"Selection and Evaluation of Methods of Hard Facing," a 12-page reprint of an article that appears in THE WELDING JOURNAL, is being offered by Air Reduction.

The major methods employed in the application of hard-facing materials are discussed, with special emphasis on the inert-gas-shielded arc process. Twenty illustrations, including photographs of overlay specimens and photomicrographs of deposits, make this booklet an easy-to-read guide in the selection of a hard-facing method for any particular application.

Request your copy by writing Air Reduction Sales Co., a division of Air Reduction Co., Inc., 60 E. 42nd St., New York 17, N. Y.

Welding Supply Directory

The National Welding Supply Assn. is currently revising its Official Membership Directory. This Directory contains the names and addresses of all Member Companies as well as the names of company executives of all Distributors and Manufacturers affiliated with the organization.

In addition, the Directory also lists the principal manufacturers each Distributor represents as well as the principal products the Manufacturer Members sell through Welding Supply Distributors.

Listing in the Directory is considered a valuable business asset by both Distributors and Manufacturers. Publication date is scheduled for immediately preceding the Assn.'s Tenth Annual Convention in San Francisco, Feb. 15, 16 and 17, 1954.

How Do They Weld?

This is the title of the 260-page report of the French Productivity Mission to the United States in October and November 1951. The report was printed by Imp. Crouan et Roques, 86 Rue de Paris, Lille (Nord) France. The 13 members of the Mission visited 31 organizations and plants from New York to Milwaukee.

The report is intended to familiarize the less progressive industries in France, those reluctant to adopt welding, with the welding methods used here to secure high productivity. Both labor-management and technical matters are discussed, with greater emphasis on the latter. The sections dealing with the different welding and cutting processes are encyclopedic in scope. If proficiency in welding can be conveyed by the written word, tables and photographs, the report must achieve its purpose. However, the Mission's most important conclusion appears to be: "The high productivity of the United States cannot be explained wholly by technical progress, but rather rests on the social, political, and economic structure." It is this structure which the Mission recommends most urgently to their compatriots.

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As easy as tuning your radio — just turn the radio-type knob of the Dial-lectric Instantaneous Remote Control (or step on a foot treadle), to adjust heat accurately. Easy, quick-start arc. No hard-working cranks to turn. No moving parts to cause delays or maintenance expense. Sizes up to 625 amps., NEMA rated. Connectable to 220 and 440 volts.

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Also equipped with hand-or foot-operated Dial-lectric Control, to give the welder fingertip heat control at the work. No hard-working cranks to turn. No moving parts to wear out. Saves on power costs under load — and during idle and no-load periods. Protects the primary input line against unbalanced conditions. Three sizes, 200, 300, and 500 amps., NEMA rated.

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Adhesive Bonding

The latest information obtained from application research in the field of using polyurethanes as adhesives for bonding rigid materials, such as metal-to-metal or glass-to-glass, is contained in a technical bulletin just published by Monsanto Chemical Co.'s Phosphate Division.

Polyurethanes are products prepared from a polyfunctional hydroxyl compound with an excess of diisocyanates. The technical bulletin lists the various raw materials and chemical reactions involved in this adhesive system, as well as principals to be followed in the preparation, curing and use of isocyanate-based adhesives. Considerable background is tabulated on the tensile strength of bonds, open-cure conditions for high-temperature bonds and metal-to-metal bonding.

In addition to the adhesive information, other applications such as surface coatings and dielectrics are covered. As a surface coating on metal foil, the foil can be creased completely due to the flexibility of the coating and the strength of the bond. A table also gives the dielectric properties of cured isocyanate-polyol films.

Copies of the bulletin, or additional technical data, are available from Phosphate Division, Monsanto Chemical Co., St. Louis 4, Mo.

Electrolytic Pressure Welding

"Electrolytic Pressure Welding," by F. Erdmann-Jesnitzer and H. Mitbauer. Abstract of "Grundlagen für die elektrolytische Pressschweissung (Pressschweissung nach kathodischer Aufschmelzung in wässrigen Electrolyten)" published in *Schweisstechnik* (Berlin) **3** (4), 101–108 (1953). The authors are associated with the Institute of Metallurgy and Materials Testing of the Mining Academy of Freiberg (Saxony). (Abstracted by Dr. G. E. Claussen.)

This article describes experiments which show the conditions under which electrolytic pressure welding of aluminum and copper wires is possible. The process consists in immersing the parts to be welded in a suitable liquid. The parts to be welded are made cathode, the anode being a carbon or platinum plate. With 220 v. between anode and cathode, and a current of 15 amp, an arc is formed between the liquid and the exposed parts to be welded. After 6 sec the ends of $^3/_{16}$-in. aluminum wire are molten and are pushed together to form a weld. The best electrolyte was found to be 1 or 2% Na_2CO_3 solution or 1 to 3% H_2SO_4. The welds had good strength and ductility. Sound welds could not be made in iron owing to hydrogen porosity. A patent on electrolytic welding was granted to W. Peukert in Germany in 1923 (D.R.P. 413,090).

Fish Eyes in Weld Metal

Abstract in *Stahl und Eisen*, **73,** 1185 (1953) of a paper published in *Arch. Eisenhüttenw.*, **24,** 361–368 (1953). (Abstracted by Dr. G. E. Claussen).

A systematic investigation was made by two German researchers, F. Erdmann-Jesnitzer and H. Kowalkowski, on the effect of coating composition of mild steel welding electrodes on the occurrence of fish eyes. They were favored by hydrogen evolving materials, such as wood flour and kaolin, and by standard ferromanganese. With properly adjusted coatings, fish eyes can be avoided. Bend and tensile tests were made on annealed and unannealed weld metal charged cathodically with atomic hydrogen. Radiographs made during the tensile tests showed the first indications of fish eyes when the stress had reached the vicinity of the yield point. The fish eyes are caused by high pressures of atomic hydrogen which diffuse into tiny holes and change to the molecular form. The kinetics of fracture of specimens containing fish eyes was studied. Back reflection X-ray photographs in fish eyes showed that they are regions of brittle fracture. Etching in dilute H_2SO_4 confirmed the X-ray results. The paper concludes with suggestions for the production and inspection of welded structures.

Solar Fluxes

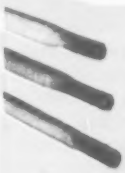
A new booklet describing Solar backing fluxes for mild and alloy steels has been published by Solar Aircraft Co.

The booklet contains drawings showing the source of common problems in alloy welding, and describes methods of using backing fluxes to obtain faster, better welds. An application chart indicates the proper type of flux to use on various types of steel with a number of welding methods.

Copies of the Solar Flux booklet can be obtained from the Flux Department, Solar Aircraft Co., 2200 Pacific Highway, San Diego 12, Calif.

P&H
Welding Equipment
speeds production schedules, cuts costs

P&H LOW-HYDROGEN ELECTRODES



13 types for high-strength welds on problem steels, steel castings, nickel-alloy steels, chrome-moly steels, .40 carbon castings, high-hardenable steels, aircraft and similar steels.

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Position heavy weldments for economical downhand welding. Complete range of sizes to handle work from 2500 to 36,000 lbs. — remote-control and hand-operated models.

P&H WN-301 Engine-Driven DC ARC WELDER

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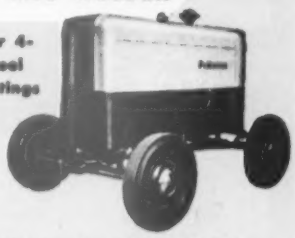

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NEW PRODUCTS

Jet Weld

The Lincoln Electric Co. of Cleveland, Ohio, has announced a new electrode which it claims is a new approach to electrode design, representing a step forward in electrode development comparable to the introduction of extruded "shielded-arc electrodes" and the low-hydrogen electrodes. The new electrode, called Jetweld, incorporates powdered metal into the electrode coating. This new type of coating uses the heat of the arc more efficiently than any other type of hand electrode to achieve the fastest hand welding speeds ever accomplished with ever higher standards of weld quality, appearance and ease of operation.

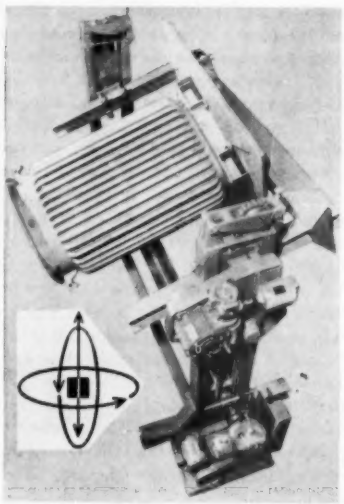
Jetweld is a heavily coated shielded-arc type of electrode for operation in flat or near flat positions with a-c or d-c welding current. It meets the physical requirements of class E-7016 and is used on work formerly calling for E-6012 and E-6020 electrodes on single-pass or multiple-pass welds. It is especially well suited for horizontal and flat position fillets, horizontal and flat position laps, single and multiple pass butt, deep grooves and corners, cover pass on multiple-pass butts. It is ideally suited for welding, without cracking and without surface holes, some higher carbon steels. Weld metal is uniform X-ray quality, free from undercut with better impact values at low temperatures than is possible with electrodes other than low-hydrogen types. Typical physical properties, as-welded, are: tensile strength, 93,000 psi; yield point, 79,000 psi; elongation in 2 in., 15 to 22%. Typical Charpy keyhole impact value at room temperature is 28-lb. At −70° F value is 20 ft-lb.

Jetweld is available in $^{5}/_{32}$-, $^{3}/_{16}$- and $^{1}/_{4}$-in. sizes.

New Positioner

Any point on a weld job can be positioned for efficient downhand welding with the new type positioner recently developed by Pandjiris Weldment Co., St. Louis, Mo.

The new positioner, called the 3MBT (3 Motor Balanced Type) provides three degrees of freedom: (1) Horizontal (Table Rotation), 360 deg; (2) vertical (Great Circle Rotation), 360 deg; and (3) elevation (moves weld job up or down). All positioning is done automatically by pressing a button. The load is swung about a neutral axis.



Its maneuverability is unlimited. The 3MBT table can be set in a low position for loading the weld job upright. It will lift the job and turn it 360 deg vertically or horizontally. . .raise and turn it completely over for welding "high" side areas... lift the job and swing the top down for welding "underneath" the top. . .tilt the work upward so you can weld the top areas by standing on a Pandjiris Weld-Evator.

Standard models of the 3MBT are available in eight different capacities. . .for positioning jobs ranging in sizes from 500 to 20,000 lb. Special sizes are available upon application.

Additional information may be obtained by writing the Pandjiris Weldment Co., St. Louis.

Manganese Bronze Rod

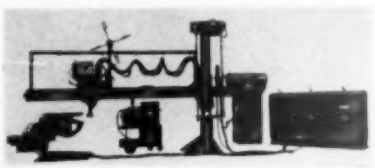
Weldwire Co., Inc., Philadelphia, Pa., has developed a new phosphor bronze, Grade C, arc welding coated electrode especially adaptable to weld *manganese bronze* material. This modified phosphor bronze electrode is an addition to the regular Weldbest 620C which is excellent for welding phosphor bronze and steel.

All-Weld-Metal tensile specimens exhibit 61,000 psi tensile strength, 32,000 psi yield strength, 45% elongation and 36% reduction of area. The Brinell hardness is about 110.

Data sheets are available from Weldwire Co., Inc., N. W. Corner Emerald & Hagert Sts., Philadelphia 25, Pa.

Automatic Welding Machine

Large mining companies, steel mills, government maintenance departments, atomic research plants and general job shops will find this new Leader Model 700 has about every feature they need in an automatic welding machine. It has a heavy-duty head, with a 1200-amp d-c current source, which can also be used individually as three 400-amp manual welders. It has two control panels: an operator's control panel located on the horizontal cross bar for easy reach, plus the main control panel. The pedestal is motorized, and has a 96-in. travel. It rotates through 360 deg and has built-in locking and limit switch controls.



The 132-in. cross-arm has an acme-actuated, variable speed reversible drive motor (20-1 ratio) for carriage transverse. Limit controls are built in.

All wiring furnished and executed to facilitate 3-phase, 220/440 v, 225/115-amp connection at point of installation.

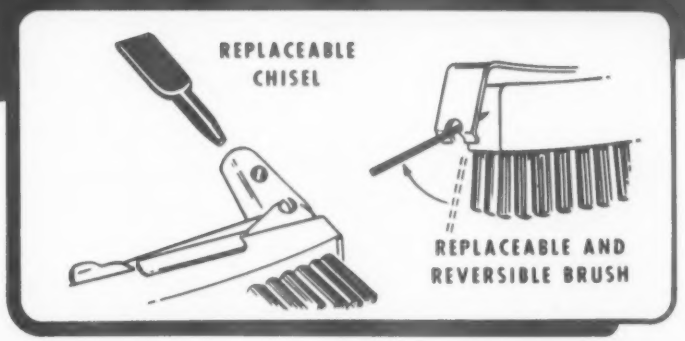
For additional information and prices please write to Leader Welding and Manufacturing Co., 2418 Sixth St., Berkeley 2, Calif.

Manifold Joint

This invention relates to improvements in manifolding and in particular to a differential dry joint for making a fluid-tight connection between two fluid conduits when assembling a manifold.

The invention may be used for joining a nipple to a pipe, a nipple to an elbow, a nipple to a valve housing, and so on. It solves the problem of securing a leak-tight joint without the use of silver solder, braz-

THE MOST PRACTICAL WELD CLEANING TOOL EVER DESIGNED!



Model B-1
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● Experience real economy with this tool that requires replacement of worn parts only! The "Re-bit" chisel can be set at any angle, has a wider edge and narrower cross section, gets into corners and pockets better, affords better vision. "Re-bit" is easier to sharpen, lasts longer . . . Ask your welding supply dealer for information on all 27 Atlas models.

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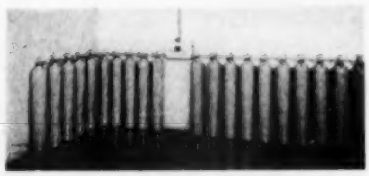
707 E. LEWISTON AVENUE FERNDALE 20, (DETROIT) MICH.

ing, litharge and glycerin, or other sealing compounds, some of which cannot safely be used with flammable gases.

The dry unsoldered joint of this invention is safe for use with highly flammable gases such as high-pressure hydrogen and oxygen or acetylene. National Welding Equipment Co., 218 Fremont St., San Francisco, Calif.

New Manifolds Allow Flexible Cylinder Arrangement

Centralization of gas supply, by means of manifolds and feed lines, saves time and money for those who use large quantities of compressed gases. Manifolding the cylinders reduces floor space requirements, cuts labor costs, eliminates many handling and maintenance costs, and increases production by providing a continuous flow of industrial gases at controlled pressures. The new line of Oxweld stationary manifolds, introduced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., features advantages that enable the user to realize the many economies of a dependable and continuous gas supply. This new line offers a wide choice of both single-regulator (M-25 Series) and dual-regulator (M-20 Series) manifolds.



The Oxweld M-20 Oxygen Manifold automatically changes gas load when one bank of cylinders is empty. It also allows unusual flexibility of cylinder arrangement. Any number of cylinders can be added to either bank at any time—and banks can be arranged to fit practically any size or shape room

Hard-Facing Electrode

A new electrode particularly suited for hard-facing various types of equipment used in many industries has just been introduced by the Stoody Co.

Under extensive field tests for a period of nearly two years, Coated Tube Stoodite has been subjected to every possible use in order to determine its suitability for equipment of all kinds. A great many users of hard-facing alloys have assisted in these tests and will recognize the product as "Experimental Electrode, Stoody 1293."

Deposition rate is far faster than can be attained with cast electrodes and the welded deposit is smooth, sound and free of pinholes or checks. With chromium and molybdenum as the principal alloys this

Crusher Tires maintained with Coated Tube Stoodite show unequaled wear properties, require less frequent "touching up"

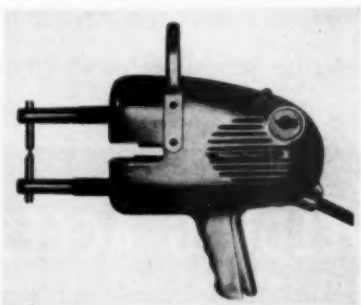
material provides especially good resistance to all types of abrasion, exhibits high compressive strength and has excellent impact resistance. Coated Tube Stoodite is readily weldable to all carbon and alloy steels including manganese. Deposits are semiaustenitic, and are not affected by ordinary heat-treat methods. Under normal welding procedure, either a-c or d-c, deposits show a Rockwell C hardness of 56–60; properties are retained at temperatures up to 800° F.

Descriptive literature is available from Stoody dealers or Stoody Co., Whittier, Calif.

Portable Spot Welder

Features electronic timing control enclosed within the unit itself. Eliminates necessity and expense of wall timer. Offers timing cycle from $^1/_{60}$ of a second to full second that takes the guesswork out of spot welding.

Welds most alloys of aluminum sheets, steel, mild and stainless, also galvanized and cadmium plated. Its output is over 10 kva. Pistol grip for easy operation and handling and especially ideal for work in those "hard-to-get-at" places. Consistently good, uniform welds as fast as operator can squeeze and release handle. Weighs only 26 lb.

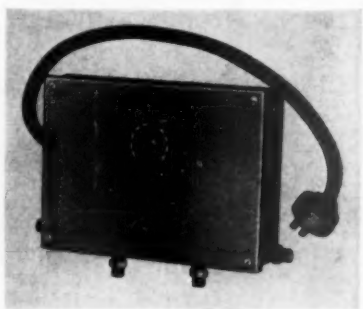


Also available is a stand into which the welder can be quickly mounted and put into use as a foot operated floor model suitable for semiproduction work.

Further particulars and complete data may be obtained without cost or obligation by writing to the manufacturer—Ampower Products Co., 5737 W. 87th St., Oak Lawn, Ill.

Gas Water Control

The new Mullenbach Gastrol is an automatic control for all inert gas welding. Its function is to limit the flow duration of both gas and water to the necessary welding and cooling periods. Automatic shutoff then overcomes human forgetfulness and resulting waste of gas and water. Since cold water circulation is stopped through the electrode holder during off-welding periods, condensation is prevented, thus eliminating contaminated welds from this source.



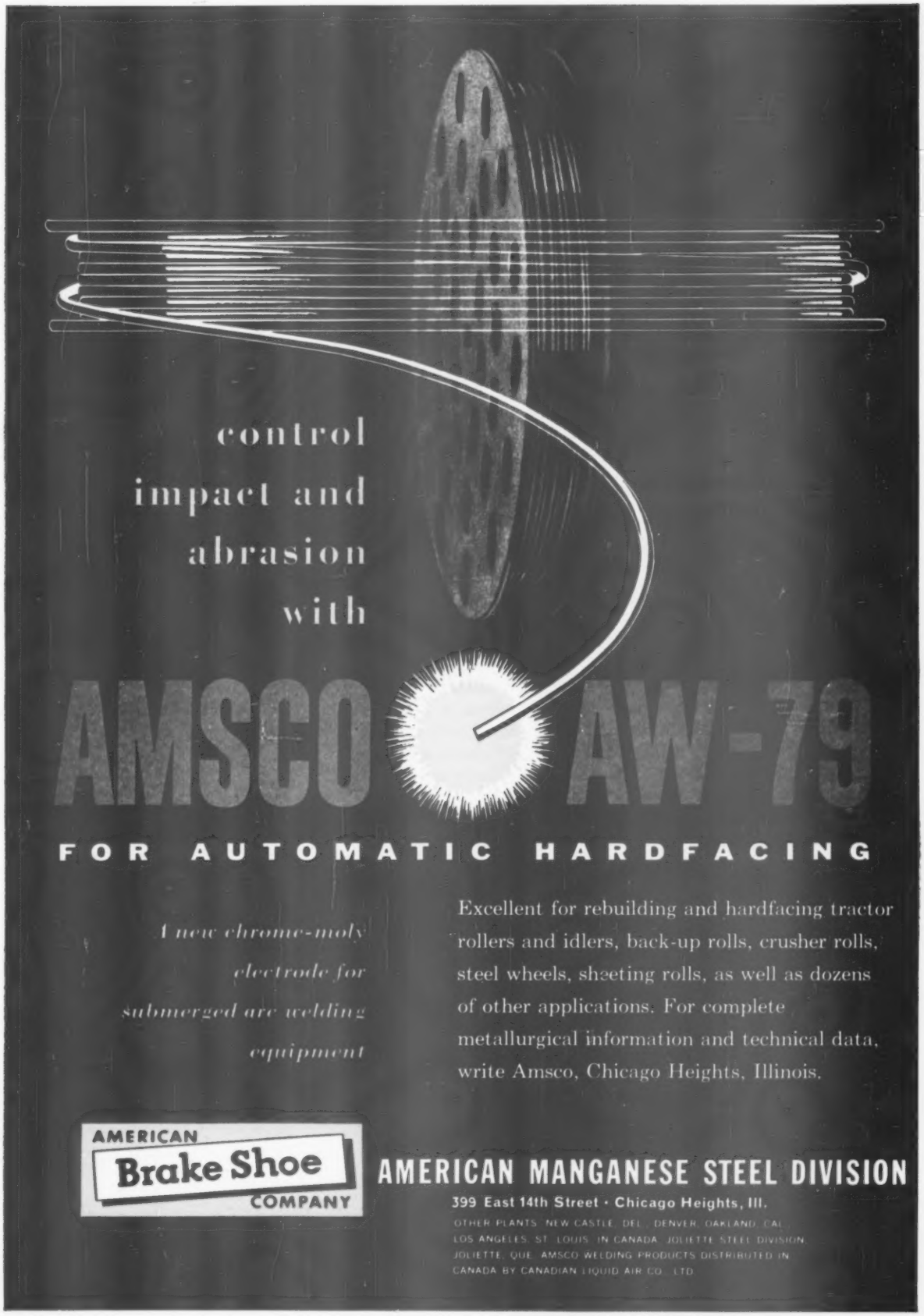
No mechanical or electrical connection exists between the Gastrol panel and welder other than an independent control system and supply hoses. The panel works equally well with a-c or d-c welders and is operated on standard 110-v a-c power. When gas and water are flowing a safety light gives positive indication.

A circular is available from Mullenbach Electrical Manufacturing Co., 2300 E. 27th St., Los Angles 58, Calif.

Aircospot (R) Gun

The Aircospot Gun, a new development by Air Reduction, is now available to industry. This lightweight spot-welding gun uses a $^3/_{32}$-in. nonconsumable thoriated tungsten electrode and an inert-gas shield. It makes instantaneous welds on stainless steels, mild steels and alloy steels, without the aid of jigs or fixtures.

The Aircospot unit consists of a hand gun, control panel and all necessary hose and cable assemblies. In order to use this equipment, a standard d-c power source, either motor generator set or rectifier type of machine, is required. The gun is water-cooled, and uses helium or argon, or a mixture of the two, for a shield.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A new chrome-moly
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Excellent for rebuilding and hardfacing tractor rollers and idlers, back-up rolls, crusher rolls, steel wheels, sheeting rolls, as well as dozens of other applications. For complete metallurgical information and technical data, write Amsco, Chicago Heights, Illinois.
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OTHER PLANTS: NEW CASTLE, DEL., DENVER, OAKLAND, CAL., LOS ANGELES, ST. LOUIS. IN CANADA: JOLIETTE STEEL DIVISION, JOLIETTE, QUE. AMSCO WELDING PRODUCTS DISTRIBUTED IN CANADA BY CANADIAN LIQUID AIR CO., LTD.

Photo at Taylor-Winfield Corp.

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HERE, while the spot welder is in operation, a Brush Analyzer records amplitude and timing of both input and welding current on the same chart. By checking the wave shapes, inspectors are able to calibrate controls quickly, and assure top quality welds at all times.

Such exact data on welding variables helps you meet specifications exactly, and gives you written proof of performance. Guesswork is eliminated.

Versatile Brush Analyzers save you time in analysis of operation of all types of spot welding machines ... and in studies of a-c or d-c voltages or currents, strains, stresses, displacements, and other static or dynamic conditions. Brush representatives are located throughout the U. S. In Canada: A. C. Wickman, Ltd., Toronto. For free bulletin write Brush Electronics Company, Dept. JJ12, 3405 Perkins Avenue, Cleveland 14, Ohio.

PIEZOTRONICS ... Brush has prepared this informative 24-page brochure describing the functions and applications of piezo-electric materials. Write for your free copy — it may spark a product development idea.

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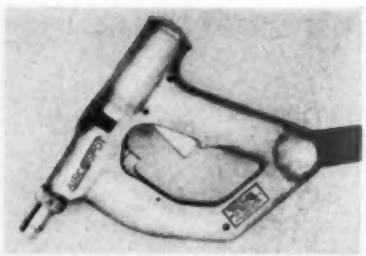


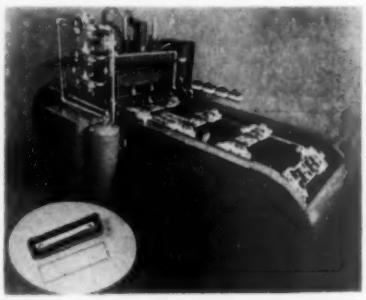
High frequency is not required. The Aircospot gun is rated at 250 amp and welds may be made on sheet metal up to 1/8 in. in thickness. The bottom section can be of greater thickness. In most cases, a backing plate is unnecessary.

The operator need only position the top sheet on the piece to which it is to be joined, position the gun and pull the trigger. The operation is completed in approximately one second.

A leaflet listing all technical data is available upon request. For further information write to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Resistance Welding Machine

A unique application of resistance welding combined with built-in automation is manufactured by the Multi-Hydromatic Welding & Manufacturing Co. Simplicity in loading makes possible a production in excess of 600 units per hour.



This particular machine was built to weld retainers to valve gasket covers. Features include a continuous chain conveyor which carries 12 fixtures moving intermittently by means of an air cylinder.

Positive location is obtained by an air-operated stop pin. When a fixture comes into the welding station, an air-operated clamping cylinder exerts a force downward on the part pushing the fixture onto locating pins and the valve cover over the backings. Twelve spot welds are made simultaneously.

Additional information as to the application of the principle to various components can be obtained by writing the manufacturer—Multi-Hydromatic Welding & Manufacturing Co., 23171 Groesbeck Highway, East Detroit, Mich.

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- INERT-ARC
- AC METAL-ARC
- DC RECTIFIER
- RAD-ARC-TROL

INERT-ARC WELDER—Combines instant starting, smooth and stable arc, compactness, and portability.

AC METAL-ARC WELDER—Patented design features high duty cycles without cooling fans, minimum "no-load" loss, smooth and stable arc. Available in models from 130 to 600 amp capacity.

DIRECT CURRENT SELENIUM RECTIFIER WELDERS—The latest development in direct current welding equipment. No moving parts—low maintenance.

Viking—the name synonymous with welding know-how—gives you a PRODUCTION ENGINEERED welder line for all your needs.

Viking welders—famous for their smooth, STABLE arc—are tops in performance under all conditions. Carefully designed—ruggedly built—rigidly inspected, Viking welders do the job economically and effectively.

Viking engineers and distributors are well qualified to assist you in determining the right equipment for your jobs—or in converting your present equipment to high-frequency or inert-arc welders.

RAD-ARC-TROL—An automatic high-frequency arc stabilizer and starter for use on ANY MAKE of AC or DC welder. Model MR is used for light gauge metallic arc welding. Model MRG converts your present welder for the Inert-arc Process. The gas regulating attachment is included in the unit.

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WEYERHAEUSER

finds many applications for the

ARCAIR TORCH

Weyerhaeuser Timber Company, at their White River operation near Enumclaw, Washington, finds many time and money-saving uses for their ARCAIR Torch.

Removing flanges from cast iron railroad wheels is an unusual application but it shows the versatility of the ARCAIR Torch and its ability to cut the hardest metals.

In converting these railroad wheels to undercarriages for heavy logging equipment the ARCAIR Torch was found superior to any other cutting method in speed, ease of operation, economy and smoothness of cut surface.

Regular jobs for ARCAIR at Weyerhaeuser are gouging iron and stainless steel castings, repairing shovel buckets, cutting all metals, removing welds, scarfing and preparing for welding or brazing. "Couldn't do without it now," says the machine shop foreman.

The new ARCAIR method slashes operating costs too, using only compressed air and an electric arc, and solves many metal removing problems for fabricators, foundries, maintenance shops and machine shops throughout the country.

Write for Free Bulletin with facts and photographs of other time and money-saving applications of the ARCAIR Torch. Arcair Company, EASTERN DIVISION, 423 So. Mt. Pleasant Ave., Lancaster, Ohio; WESTERN DIVISION, P.O. Box 4107, Bremerton, Wash.

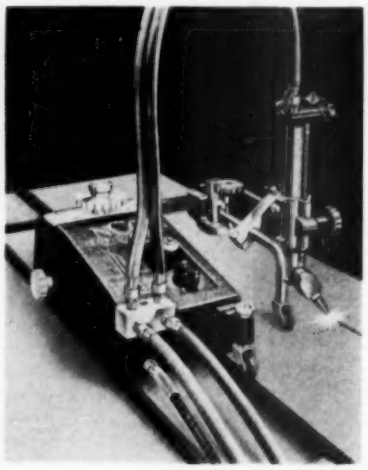
Arcair **TORCH**

Cuts all metals—using only electric arc and compressed air

Floating Torch

A new "Floating Torch" assembly which permits uniformly accurate bevel cutting regardless of humps, bows or other unevenness in steel plate has been developed by National Cylinder Gas Co. for use with its "Cut-O-Matic" portable cutting machine.

The new unit has two principal parts: a guide wheel and a newly designed beveling torch.



The guide wheel, which rests on the plate being cut, controls the distance between the torch tip and the plate. It automatically raises or lowers the torch to compensate for any unevenness present in the plate which otherwise would change the line of the bevel.

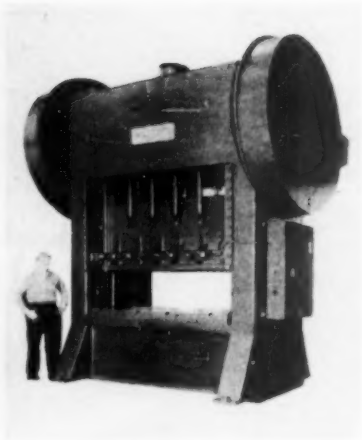
The new torch is equipped with a swivel head which permits the tip to be rotated to cut whatever angle of bevel is required for subsequent welding operations.

The "Cut-O-Matic" to which the torch is attached is a motor-driven cutting machine weighing less than 50 lb. It cuts straight lines, circles, arcs, rings, strips and various irregular shapes. It can be used on steel plate, slabs and pipe. It will cut thicknesses up to 7 in. with a standard two-hose torch and up to 16 in. with a special three-hose torch. Special adaptations of the machine are used for automatic gas welding and heating operations.

Wickliffe Presses

The Cleveland Crane & Engineering Co., Wickliffe, Ohio, announce their entry into the heavy press field with the introduction of a completely new line of presses ranging from 160-ton capacity and up.

The new machines, to be known as Wickliffe Presses, will supplement the Steelweld Bending Press and Shear lines which were originally developed and introduced by the company many years ago and are now in extensive use. They are intended for uses such as forming, blanking, piercing, trimming, light embossing and drawing.



Frames are straight-sided and consist of four members—crown, two-side housings and bed—held solidly together by tie rods shrunk in place. All members are "box-type" and of heavy all-welded steel construction.

Slide adjustment is of the modern barrel type. It provides extra stability, especially desirable on long adjustments. The entire adjusting unit is compact, self-contained and very easily removed from or assembled to the slide.

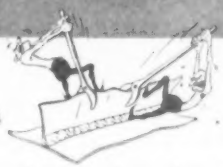
Connector Soldering Machine

Joyal Products, Inc., 115 Edison Place, Newark 5, N. J., announces that its 250-w AN Connector Soldering Machine is now being made with soldering tweezers, as well as the regular soldering electrodes. This innovation gives the equipment almost universal versatility for the soldering of small parts on a production basis. The machine, complete, is priced at only $125 F.O.B., Newark, N. J.

The other fixed electrodes can solder from 2 to 30 terminals, and more, on AN Connectors. They can also be used on terminal boards, on printed circuits with high-temperature solder that cannot be handled with a soldering iron, and for military equipment on solder-crimped lugs, to government specifications.

Low Temperature EUTECTIC WELDING ALLOYS

stops mild steel welding failures

minimize stress  ...distortion ...warpage with Low Temperature EUTECTIC WELDING ALLOYS

impossible?...that's what the Stolper Steel Products Corporation thought, too, until they actually tried these **new,** entirely different EUTECTIC "Low Amp"® EutecTrodes.® Then they came up with the astounding Case History shown below...Yes, we not only **claim** this amazing performance...we **prove** that "Eutectic" is different...prove that these new alloys **solve** metal-joining problems **where conventional materials fail!**...Let us prove it in your shop...just as we have in over **78,000** other plants and shops throughout America...There's no cost, no obligation involved...just fill in and **mail** the coupon below for a **free** consultation-demonstration from one of our 350 trained District Engineers who stand ready to serve you from coast to coast.

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TIME SAVINGS PER 100 TANKS!

Airtack and weld complete..43.7%
Wire Brush welds.....18.6%
Test and Repair leaks.....32.6%

"This reflects a savings of 43.85 hours (40%) per 100 tanks. The comparisons were made on production runs and the hours per 100 tanks shown are actual time study standards used for incentive purposes.

"I wish to thank you for the splendid cooperation which made this savings possible."—*L. L. D., Ind. Eng., Stolper Steel Products Corp.*

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NEWS OF THE INDUSTRY

1954 IAA Convention

The 1954 International Acetylene Assn. Convention will be held in Chicago on April 7th, 8th and 9th at the Palmer House. The Publicity and Arrangements Committee met in Chicago with representatives of member companies in that city. Much progress was made in developing the technical part of the program. The Convention plans are off to a good and an early start, with all indications that next year's meeting will be outstandingly instructive, constructive and enjoyable.

International Institute of Welding

The International Institute of Welding will hold its Annual Meeting in Florence, Italy, on May 15 to 23, 1954.

Registration will take place on Saturday and Sunday, May 15th and 16th. The Annual Meeting will be formally opened on the morning of Monday, May 17th, in Palazzo Vecchio (the historical Town Hall of Florence).

In the afternoon of the same day the Public Session will take place in the Sala Bianca of the Pitti Palace where papers on the following subject will be discussed: Welding in Rail and Road Transport. The Italian, French and English languages are admitted for this session; texts in the original languages and summaries in other languages will be sent to all members beforehand. All members may attend this session as well as the technical films on welding to be shown on the morning of Tuesday, the 18th and Saturday, the 22nd. Meetings of the 15 Technical Commissions will take place in the Palazzo Strozzi from Tuesday to Friday and may be attended only by Members and Experts of these Commissions.

During this week several subscription visits to the city and its surroundings will be organized for the families and those members not engaged in the work of the Technical Commissions.

On Tuesday evening all members and their families will be invited to a reception given by the Province of Florence in the Palazzo Medici-Riccardi; on Wednesday afternoon Conte G. De Micheli and the Societa Metallurgica Italiana will give Garden Parties, and on Thursday evening an official banquet will be given by the Italian Institute of Welding.

On Thursday afternoon and Saturday industrial visits will be organized in Florence and in other places of Toscana.

On Sunday two touristic excursions will be organized to the most beautiful places of Toscana.

Other tours and industrial visits to the most important Italian cities will be organized during the week following the Meeting in Florence, with departure from Florence on Monday morning, May 24th. Industrial visits will include steel works, shipyards, mechanical, boiler, structural, motor car and railway construction works, and research laboratories.

Enrollment is to be made by sending two copies of the enrollment forms duly filled in and signed, and including a confirmation that enrollment fee has been paid to: IIW - IIS, Comitato Organizzativo Italiano, Casella Postale, 196-Firenze (Italy).

The participation fee as well as the enrollment fee are fixed per person in Italian currency and are approximately as follows:

	Participation fee	*Enrollment fee*	*Late enrollment fee*
Members of IIW and of Member Societies	$9.60	$3.20	$6.40
Persons accompanying the members	6.40	2.40	4.80

The enrollment fees are to be sent to the Banca Commerciale Italiana, Agenzia No. 1, Firenze, in favor of the Comitato Organizzativo Italiano (Italian Reception Committee), or to any other Italian bank having a branch office in Florence.

The enrollment forms, together with confirmation of payment, are to be sent as soon as possible, and in any event *not later than the 31st of December, 1953*, owing to the difficulties in booking hotel rooms in the month of May due to a musical festival to be held in Florence. Enrollment made after Dec. 31, 1953, will not be returned in case of cancellation. Furthermore the Italian Reception Committee does not take any responsibility for hotel reservations applied for after December 31st.

For further information contact J. G. Magrath, Secretary, AMERICAN WELDING SOCIETY.

1954 Welding and Cutting Exhibition

This exhibition is organized by the "Gemeinnützige Ausstellungsgesellschaft m.b. H." (Exhibition Society Ltd.), at the "Grugapark" exhibition site, Essen, from June 12 to June 21, 1954. The space which was available for the 1952 DVS exhibition "Welding and Cutting" has been greatly extended, including 10,000 sq ft covered hall space and 50,000 sq ft open space. The great interest shown during our previous exhibitions, which are probably the largest welding exhibitions in Europe, gives rise to the hope that the 1954 exhibition will attract still more exhibitors and visitors, manufacturers and users of welding and cutting equipment, from Germany and from abroad. During the exhibition the welding Engineering Conference will take place in Essen.

National Welding Supply Assn.

Fifty-four Active and Associate Members of the National Welding Supply Assn. attended an informal Luncheon Meeting at the Hotel Cleveland, Cleveland, Ohio, Thursday, October 22nd, during the Metal Show.

William A. Rice, Virginia Welding Supply Co., Charleston, W. Va., President of N.W.S.A. and James N. Alcock, Saginaw Welding Supply Co., Saginaw, Mich., Vice-President of NWSA, representing the Central Zone, spoke briefly. Both gentlemen expressed pleasure at the excellent turnout and urged those present to arrange to attend the Assn.'s Tenth Annual Convention that will be held at the Hotel Fairmont, San Francisco, next February.

Tube Turns, Inc., Adds to Staff

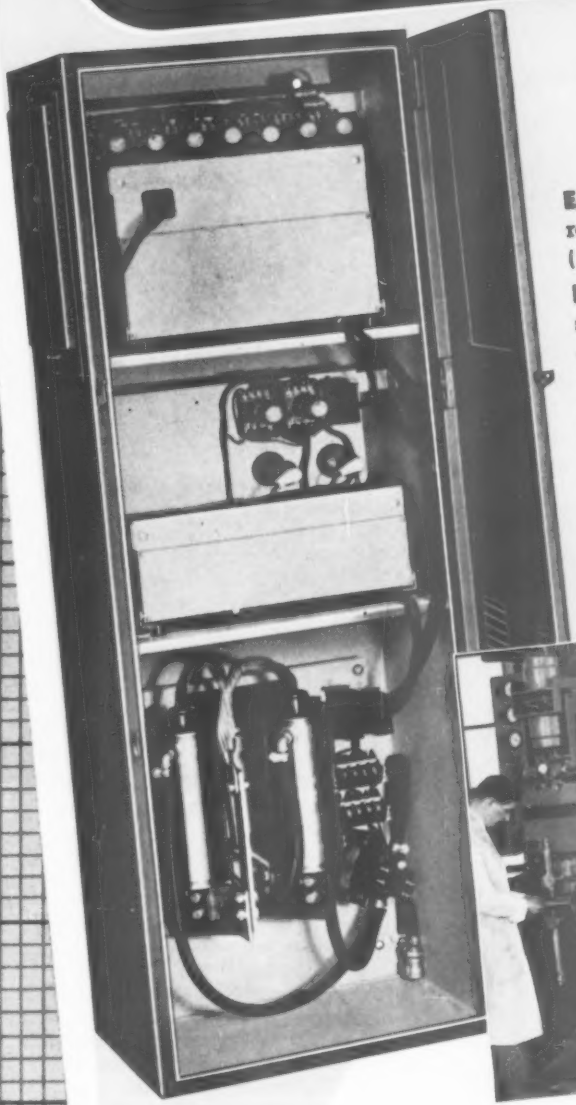
Two sales-engineering representatives have been added to the staff of Tube Turns, Inc., Louisville, Ky. They are Bert Grant, assigned to the Pittsburgh Office, and Clyde Chronister, assigned to the Tulsa office.

Bert Grant is a native Clevelander. During World War II he served as a test pilot and base commander. He was formerly associated with Capital Airlines, Associated Investment Corp. and Williams & Co. He joined Tube Turns, Inc., in July 1953. He is a member of the American Society for Metals, the AMERICAN WELDING SOCIETY and active in the Reserve Officers Assn. He will make his headquarters in the Chester Building, Cleveland.

Clyde Chronister was born in Prague, Okla. He attended Tulsa University, where he starred in basketball. Prior to becoming associated with Tube Turns, Inc., in June 1953, he was the Orbit Valve Co.'s representative east of the Mississippi.

Stainless Steel? Aluminum? Magnesium? Air-Hardenable Steels? Low Carbon Steels? Aluminum-Magnesium Alloys?

What's Your Precision Welding Problem?



Square D has the control to meet your exact needs!

Easier maintenance Vastly simplified circuits require fewer tubes and only one operating relay (for the air valve).

Increased dependability Components designed specifically for industrial welder service. Tube circuits are fail-safe. Initiating contacts are in isolated 24-volt circuit.

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Thomson Electric Welder Company Puts Square D Control to "Acid" Test

• This Thomson Welding Machine is used for experimental and "special" jobs in the Thomson laboratory. It has put Square D control to the "acid test" in scores of precision operations. It has made crack-free welds in a variety of aluminum alloys in gauge thicknesses up to .072". It has made excellent welds in air-hardenable steels and in ½" diameter steel bars.

Write for Bulletin 8993. Address Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin. Or consult your nearby Square D Field Engineer.

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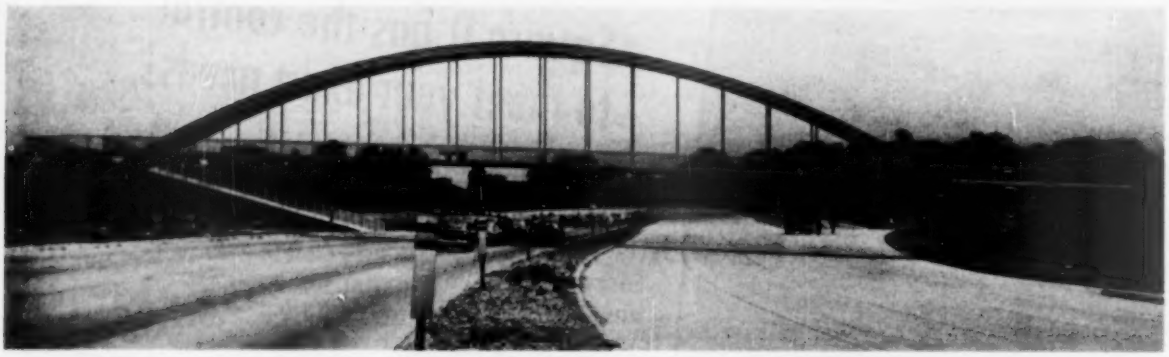
Neches River Bridge, Beaumont, Texas



Predestrian Overpass, East Memorial Shoreway, Cleveland, Ohio

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Welding Helps Bridge Winners

A bridge in Texas, was selected as the most beautiful steel bridge in the country opened to traffic in 1952 in the American Institute of Steel Construction's 25th annual Aesthetic Bridge Competition in Class II.

The Winners

Class II, for bridges with spans under 400 ft, costing over $500,000:

Neches River Bridge, Beaumont, Tex. Owner, State of Texas; designer, Texas Highway Department; fabricator, Bethlehem Steel Co. "This bridge was chosen for its clean design which is devoid of extraneous ornamentation. It has serene and graceful lines." A little more than half of this structure (2099 linear ft) is continuous I-beam construction involving 1700 tons. All cover-plated beam flanges, diaphragm and beam splices are shop and field welded in this portion. The balance of the bridge (1722 ft) is continuous plate girder construction weighing 2440 tons, is shop and field riveted except that the field connections for the bracing are welded.

Class III, Honorable Mention:

Pedestrian Overpass, East Memorial Shoreway, Cleveland Ohio. Owner and designer, Ohio Department of Highways; fabricator, The Mount Vernon Bridge Co. "The gay, light construction of this bridge, in keeping with its use for light pedestrian traffic, contributed to its selection as a winner." All shop and field connections were welded.

This joint must carry water at 500°F and 1600 p.s.i.

RADIOGRAPHY says the weld's sound

To gain top efficiency, modern power plants are operating at higher pressures and higher temperatures—conditions which call for utmost dependability in the welded joints of the piping.

Here radiography is invaluable; it alone can prove the soundness of the welds.

In this way radiography has opened new fields to welders. In high pressure piping, in the manufacture of pressure vessels, and in other applications where welding was once banned, it is now an accepted procedure.

Radiography can help you build business as well as earn a reputation for highly satisfactory work.

If you would like to know more about what it can do for you, talk it over with your x-ray dealer.

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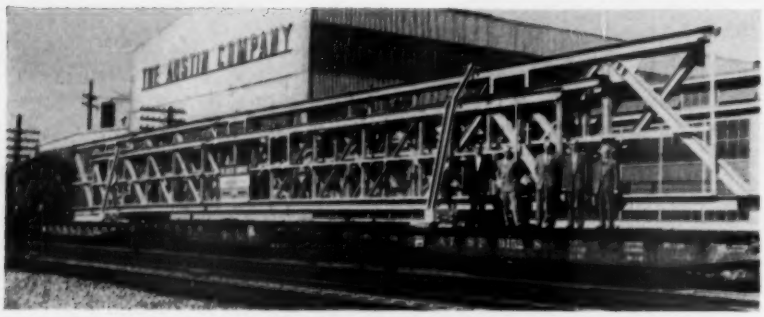


Longest Structural Steel Truss

Steel Truss

The longest structural steel truss ever shipped by rail from Cleveland, Ohio, as a complete unit, arrived safely at the Colgate-Palmolive-Peet manufacturing plant in Jersey City, N. J. this week after an 8-day, 612-mile trip.

Part of an extensive interplant materials handling installation designed by The Austin Co.'s New York District, the 135-ft span truss was fabricated by the company's Structural Steel Fabricating Division in Cleveland and transported by the Nickel Plate Road on daylight only, under 20-mile-an-hour orders, over its own tracks and those of the Lehigh Valley Railroad.

The truss is distinguished by its unique construction and the complete absence of joint plates. Its design is of the all-welded Austin originated H-section type, which reduced its weight and increased its rigidity, an important factor in shipping and erecting the complete assembly.

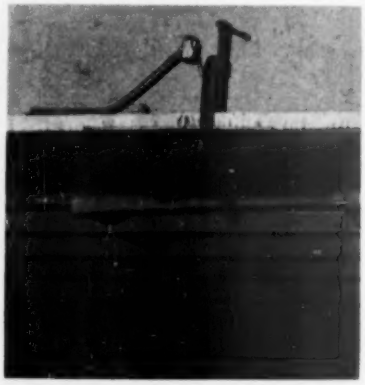
With it were loaded five other trusses of similar design but of somewhat shorter spans, on three flat cars (one 45 ft, two 52 ft). The shipment weighed about 45 tons which was not a factor in itself, but presented a unique problem of loading, handling and holding down because of the extensiveness of the mass and the low tonnage.

Destined to become part of a new conveyor system which will connect several multistoried buildings at the Colgate-Palmolive-Peet plant, the truss was fabricated in one piece in the Cleveland plant of The Austin Co. because of lack of sufficient space at the site in Jersey City to permit partial assembly on the ground.

Other units for the extensive conveyor system are now being fabricated by The Austin Co. but these will involve no unusual shipping problem. The conveyor, when installed, will be located at heights of 60 to 80 ft above the ground.

Use of Cobalt 60

Huge steel beams of a building were X-rayed on the University of Illinois campus recently with an amount of radioactive cobalt so tiny that it was hardly visible to the naked eye. E. L. Stouffer, the University of Illinois supervising architect, explained the x-rays were necessary to determine the safety of a 60-ft square underground room that will accommodate about 260 persons who would be endangered if any of the welds in the fabricated steel beams were defective.



The tiny capsule of Cobalt weighing less than a gram ond still enclosed in a small container, was attached to the top of the beam so that it could shoot rays through the 1½ inches of steel on to the film below

To make such X-rays usually involves heavy equipment which is not portable. Therefore, Prof. George L. Clark of the University of Illinois Chemistry Department suggested the use of Cobalt 60, one of the products derived from atomic activity at Oak Ridge, Tenn. Prof. Clark contacted C. L. Darling, General Manager of X-Ray Inc., a Detroit firm that is pioneering in the usage of Cobalt 60. Darling immediately dispatched a truck and a crew of technicians to the University of Illinois with an amount of Cobalt 60 weighing less than a gram, but so radioactive that it was carried in two lead containers weighing more than 300 lb. However, when the actual X-raying was done

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there was no heavy complicated equipment which is usually necessary to take an X-ray. Instead, just a small capsule of Cobalt 60 was clamped on top of a 1½-in. steel beam and X-ray film stuck on the underside of the beam with plain old adhesive tape.

Only other equipment was a Geiger Counter which clicked away with warnings of radioactivity. When the film was developed a large cavity was discovered in one of the welded joints of a beam that was to eventually bear the main stress of the building.

Water Taxi

Equitable Equipment Co., Inc., of New Orleans, just delivered this 38-ft 6-in. Water Taxi to Capt. Harry L. Hargrove, the President of the Mobile Bar Pilots' Assn. Although very similar, it possesses slight modifications to the Standard Equity Crew Boats which are widely used in offshore and inshore oil operations throughout the world.

The new Water Taxi designed by Equitable attains a speed of 28 mph and requires an operating crew of only two. Actually, it is a one-man control vessel—the second crew member is merely a deckhand.

This sturdy little all-welded vessel has an over-all length of 38 ft 6 in.; 12-ft 6-in. beam; and a draft of 3 ft 2 in. It has a displacement of 13½ tons light, and 15 tons loaded. Its facilities and outfitting are on par with the finest custom-built yachts, yet it offers the maximum in safety, ruggedness, low maintenance and versatility. Accommodations for six are available along with a galley, refrigerator, two heated cabins and a complete lavatory.

In furnishing these many features, economy of operation was still maintained. This speedy, sturdy craft consumes less than ½ gal of fuel per mile. Its current base of operations will be Fort Morgan, Mobile Bay.

Awards for Welded Designs

Young mechanical and structural engineers in 16 states and three engineering schools have received national recognition through The James F. Lincoln Arc Welding Foundation of Cleveland, Ohio. The Foundation has announced the 1953 awards for engineering undergraduate papers on welded design of machines and structures. Forty-six cash awards ranging from $25 to $1250, and totaling $5000, were presented to 51 undergraduate engineers in 21 different engineering schools. Scholarship funds totaling $1250 were granted to schools.

The First Award of $1250 was given to Co-authors, Clayton Wilkie and Henry Cohen, who, as undergraduates in the Civil Engineering Department of New York University prepared a paper describing the "Design for a Welded Continuous Curved Girder Highway Bridge." As additional recognition, the Foundation presented the New York University with $1000 to be used for scholarships named in honor of these students.

Thomas J. Feaheny, Jr., described the "Design of Material Handling Containers for a Forge Shop," to receive the Second Award of $1000. The Mechanical Engineering Department of the University of Detroit received $500 in scholarship funds honoring this achievement.

William J. Chancellor, as an agricultural engineering student at the University of Wisconsin, received the $500 Third Award. He described the "Design and Construction of a Chain Mower." The University of Wisconsin received $250 for a scholarship in his honor.

The purpose of these awards, according to Dr. E. E. Dreese, Chairman of the Foundation's Board of Trustees, is to encourage engineering students to study how machines and structures made of steel can be improved and reduced in cost by the application of arc welding in their design. Awards are made annually for the best papers describing the use of arc welding in the design of a machine or structure. All engineering undergraduates are eligible to participate. The rules for participating in the 1953–54 program are available from The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio.

the D-C Rectifier Welder with ARC-DRIVE CONTROL

. . . INSTANTANEOUS RESPONSE TO ARC-LOAD CHANGES
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Westinghouse RA Welders with new positive arc-drive control now prevent shorting when used on "drag" welding applications. In addition, they allow complete penetration on root passes of vertical and overhead welds. Arc-drive control is obtained by adjusting the ratio of short-circuit current to welding current without changing open-circuit voltage. Actual amount of arc-drive current can be varied by the operator.

For information on this improved RA Welder or other Westinghouse Welding Equipment, write Westinghouse Electric Corporation, Welding Division, P. O. Box 868, Pittsburgh 30, Pennsylvania.

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Notice

Due to the Christmas Mailing Volume we have been cautioned not to send out our Buffalo Hotel Reservation Form just prior to then. Therefore they will be mailed immediately after Christmas. Processing and acknowledgment from Buffalo Hotels will commence Feb. 15, 1954 as previously scheduled.

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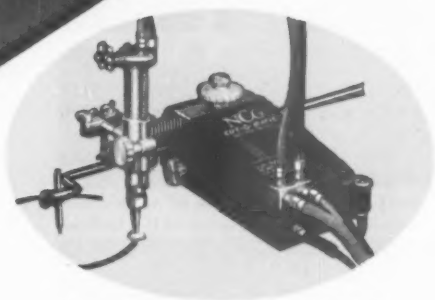
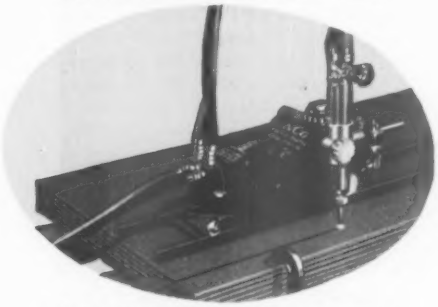
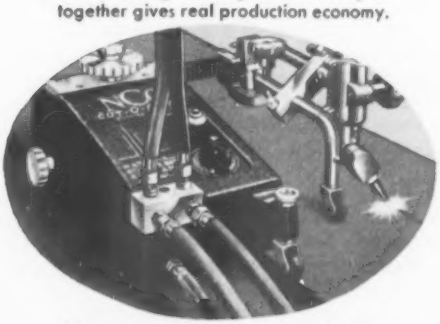
Cut-O-Matic weighs only 50 lbs. It is taken to the work, used wherever power is available. Motor-driven and track-guided, its operation requires no special skill. Its flame slices through steel leaving a clean sharp edge and surface. It cuts steel plates, stacked sheets and heavy slabs. It cuts on the square or bevel, it cuts straights, circles, strips, and rings.



Cutting Circles and Arcs from 3 to 60". Rings can be cut with two-torch mounting.



Stack Cutting. Cutting sheets clamped together gives real production economy.



New "Floating Torch" automatically cuts accurate bevels on steel plate.

NOW! NEW FLOATING TORCH ASSEMBLY ASSURES PERFECT BEVEL CUTS ON CURVED OR WAVY PLATES

To bevel accurately plates with wavy or bulging surfaces, NCG now offers its new Floating Torch Assembly that automatically results in perfect bevels (see illustration at left). Contour wheel raises or lowers new swivel-head beveling torch to compensate for unevenness of plate surface, holding torch tip at same angle and distance from plate. Permits new *ease* and *economy* in plate preparation.

As the first step toward more profitable metal working, have versatile, useful Cut-O-Matic and the new Floating Torch Assembly demonstrated in your own shop. Contact your nearest NCG district office or authorized NCG dealer. No charge or obligation. Illustrated Booklet N-134 is yours on request. Write today.

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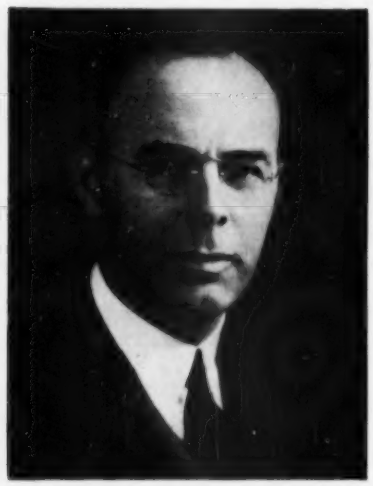
PERSONNEL

H. Malcolm Priest Made Honorary Member

At the Annual Dinner of the AMERICAN WELDING SOCIETY held in Cleveland on October 22nd, H. Malcolm Priest, Manager of the Railroad Research Bureau of the United States Steel Corp., was awarded honorary membership in the AMERICAN WELDING SOCIETY. In bestowing this honor upon Mr. Priest, the Committee stated: "H. Malcolm Priest pioneered in the welding of structural steel and prepared for the SOCIETY the text for a book entitled *Practical Design of Welded Steel Structures*, and served the SOCIETY faithfully and effectively in many capacities and on the Board of Directors for a period of six years."



Mr. Priest was born on July 23, 1890, in Malden, Mass. He graduated from the Massachusetts Institute of Technology in 1912 with the degree of S.B. in Civil Engineering. Mr. Priest spent three years with the Rock Island Lines in Chicago as a designer of track elevation. He then joined the U. S. Air Force at McCook Field in Dayton Ohio, and spent two years in research work for that organization. The following two years were devoted to teaching at Purdue University where he held the post of Assistant Professor in the Civil Engineering School. In 1919 he joined the American Bridge Co. and worked in their Elmira, N. Y., plant as draftsman and checker. He was transferred to New York City as designing engineer. During his service in New York City, he was connected with the design and construction of some of the first welded steel structures. He was Vice-Chairman of the AWS Structural Welding Committee in charge of the extensive test program conducted by the Committee which formed the basis of the AWS Building Code. In 1933, Mr. Priest was transferred to the Research Bureau of the U. S. Steel Corp. as Engineer and he later became Manager of this Bureau for the Corporation.

His AWS activities have been numerous and varied. The following are some of the significant positions which he has held: Two terms on the Board of Directors of the AMERICAN WELDING SOCIETY, Chairman of the New York Section from 1931 to 1932. He served on the Structural Steel Welding Committee, Committees on Symbols, By-Laws, Awards, Nominating and Technical Activities. He has contributed some ten papers to the SOCIETY and has delivered talks before a number of Sections.

James L. Head Elected UET President

United Engineering Trustees, Inc., elected officers for the ensuing year, naming James L. Head as president, succeeding R. F. Gagg, president for the past two years. Mr. Head is mining engineer with the Anaconda Copper Mining Co. He has been active in the work of the American Institute of Mining and Metallurgical Engineers whom he has represented on the Board of UET since 1947. He was chairman of the Engineering Societies Library for the past two years, and vice-president of UET. He is a past-president of the Mining and Metallurgical Society of America. John H. R. Arms was re-elected as secretary and general manager, a position he has occupied since 1933.

Peck Appoints Sales Engineer

The appointment of Harry F. Prah as Sales Engineer for the Cecil C. Peck Co. has been announced by W. A. Dewald, Sales Manager.

Mr. Prah, who will have headquarters in Indianapolis, is a member of AWS and a board director of the YMCA and received his B.S. degree in Industrial Engineering at Penn College. He has a wide experience in the industrial field principally with Bryant Heater at Cleveland, Tyler, Tex., and Indianapolis. Besides pioneering in new galvanizing and welding techniques, he has filled positions from junior engineer through tool engineer, chief inspector and plant engineer.

Prah's experience in general industry coupled with his vast knowledge of the welding process should be of considerable benefit to those companies in the Indiana area who wish to take advantage of his services.

Otto Graf

On July 28, 1953 Professor Graf completed 50 years of activity in the field of materials testing. Three weeks earlier the Technical College of Stuttgart, Germany, had renamed its laboratories for research and testing of structural materials the "Otto Graf Institute." A large part of his career was devoted to strengthening these world-renowned laboratories. The Structural Engineering and Design Division of the College, acting with the German research and technical societies in the building field, have issued a book *Otto Graf—50 Years of Research, Teaching, and Testing*, which describes his life work.

Prof. Graf began his career as assistant to Prof. Bach at the Materials Laboratories in Stuttgart in 1903. He published his first paper in 1908. Since then he has made a total of 620 contributions to technical literature. His work dealt with steel, reinforced concrete, cement, wood and structural glass.

Prof. Graf began his work on steel after the first World War. He realized that fatigue strength is an important factor in

Made to Last by Hard-Facing

19 LIVES FOR CONCRETE MIXER BLADES

Concrete mixer blades hard-faced with HAYSTELLITE tungsten carbide rod have 19 times the life of unprotected cast steel blades. The hard-faced blades, used in making concrete blocks, now give 20 months of tough service operating 24 hours a day, six days a week. Unprotected blades had to be replaced every four to five weeks.

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This mud gun screw lasts for 8 to 10 months after being hard-faced with HAYNES STELLITE alloy No. 1. A single application of HAYNES STELLITE hard-facing rod eliminates at least seven shutdowns for repair. The screws previously had to be built up every month with steel rod because of severe wear on the flights.

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Hard-faced teeth on ditching machines last from two to three times longer than unprotected ones. Hard-facing with HAYSTELLITE tube rod gives the teeth the added abrasion resistance needed to tear through clay, sand, shale, sandstone, rocks, and fragments of paving material. It takes only 40 seconds per tooth to apply the rod on this special jig.

Hard-facing can solve many of your maintenance problems. For more information, contact the nearest Haynes Stellite Company office.

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design, and that fatigue tests on machined specimens have limited value. In 1929 his results on fatigue of riveted joints were published. In 1931 he published his famous paper "The Fatigue Strength of Steels with Mill Scale with and Without Holes, Welds and Rivets." These and later results were for many years the basis of all fatigue specifications. His tests provided a strong impetus toward the improvement and application of welding in steel structures.

National of California Promotes H. L. Pohndorf

George Hammon, Vice-President and General Manager of the National Welding Equipment Co., of San Francisco, Calif., announces the appointment of Henry L. Pohndorf ("Hank" to his many friends) to the position of Sales Manager.

Mr. Pohndorf has been with the company some seven years and in the welding industry for over a dozen years. He is a graduate Engineer of MIT and has been the Company's Chief Engineer since first joining the staff. He will retain this important job in addition to his new one. It is thought that his extensive knowledge of all of the production phases entering into the company's numerous items for both the Medical and the Welding Industries will aid very materially in the creation of proper distributor relationship which this rapidly expanding company feels so essential to earn and to hold.

Spring Meeting
American Welding Society
May 4–7, 1954
Buffalo, N. Y.

Employment Service Bulletin

Positions Vacant

V-303. Assistant to Chief Inspector. Engineering degree required. Experience in metal fabrication such as heat treating, forming, machining of welding. Must be familiar with Pressure Vessel and Power Piping Codes. Will be responsible for special projects relating to the technical skills of the Inspection Department. Will assist Chief Inspector in maintaining liaison between Engineering and Production Departments for proper interpretation of Specifications and Drawing Tolerances. Age limit, none. Salary open to $6000 depending upon experience and qualifications. To begin as soon as possible. Location, Dunkirk, N. Y.

V-304. Welding Development Engineer. Welding, Mechanical, Metallurgical, Electrical or Industrial Engineering degree or equivalent experience required. At least three years' experience in Welding Engineering development. Responsible for conducting tests and reporting on the applicability and economy of new or improved welding methods, equipment and techniques. Develop procedures and write specifications for welding new materials and designs. Age limit, none. Salary open to $6000 depending on experience and qualifications. To begin as soon as possible. Location, Dunkirk, N. Y.

V-305. Junior Engineer—Welding. Degree or equivalent experience in Welding. Mechanical, Metallurgical, Electrical or Industrial Engineering. Some practical experience desirable. Assist Welding Engineers on development, specific shop problems, welding procedures and specifications. Age limit, none. Salary open about $350 a month depending on experience and qualifications. To begin as soon as possible. Location, Dunkirk, N. Y.

V-306. Welding Supervisor with some practical experience and ability to solve welding problems in fabrication of manganese, low-chrome alloys and stainless steels. Will be in charge of instruction of several welding shops as to correct procedures and work with engineering and production departments in cast dipper and dragline buckets.

Services Available

A-643. Welding Inspector, 34 years of age, college graduate, experienced as welder, foreman, welding inspector including mild steel, stainless steel and alloy piping; also in structural work. Experienced in destructive and nondestructive testing welds. Familiar with all processes of welding and brazing of ferrous and nonferrous metals. Knowledge of metallurgy, heat treatment, boiler code, piping code, testing and training welders. Familiar with marine and maintenance welding. Will accept position anywhere as inspector or engineer.

A-644. Welding Supervisor, 23 years in welding field, last 14 in supervision of welding and cutting and related crafts. Nine years with two major oil companies in South America. Thorough knowledge fabrication of mild steel plate and pipe, low- and high-alloy materials; visual, Magna-Flux and X-ray inspection. Ample job-shop and ship repair. Interested in foreign or domestic employment. Family man and good habits. Résumé upon request.

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Austin Division

Austin, Tex.—Percy V. Pennybacker, one of Austin's outstanding professional engineers, was elected chairman of the newly organized local AMERICAN WELDING SOCIETY group.

Meeting at Randy's Circle R Barbecue, members of the AMERICAN WELDING SOCIETY here voted to become the *Austin Division* of the Houston Section, AWS, until their membership reaches 50. Then they will form an Austin Section.

A 1917 civil engineering graduate of the University of Texas, Mr. Pennybacker has been associated with the Texas Highway Department for 19 years.

Supervising field engineer in the Bridge Division of the Highway Department, he was recently named recipient of a $500 award by the Western Assn. of State Highway Officials and Western Construction magazine for his work in stressing the economy of welding in repair, strengthening and construction of highway bridges.

Mr. Pennybacker is a member of numerous technical societies, among them the American Society of Civil Engineers. He is completing his third year as Travis Chapter director on the state board of the Texas Society of Professional Engineers and has been a director in the Houston Section, AMERICAN WELDING SOCIETY.

Other officers of the Austin Division elected at same time are: Ed Garland, owner of Alamo Welding Supply Co., vice-chairman; G. B. Harton, shop superintendent of Walter Tips Engine Works, secretary-treasurer; G. L. (Duke) Wiley, welding specialist in the Austin office, THD, and Frank W. McBee, Jr., research engineer, University of Texas Defense Research Laboratory, directors.

In Austin to help conduct the meeting were three officers of the Houston Section: W. H. Greer, Houston chairman; James Earthman, vice-chairman; and John C. Cassidy, director.

Harry F. Reid, Jr., manager of the technical service division, The McKay Co., of York, Pa., made the principal address.

Attending on their own initiative were men interested in welding from several other Central Texas towns, among them two San Antonians.

Hortonsphere

Bethlehem, Pa.—Approximately 50 members and guests were present for the dinner at the opening meeting of the *Lehigh Valley* Section, held on Monday, October 3rd at Walp's Banquet Hall, Allentown, Pa. After the dinner, a colored sound film was shown entitled "Inland Voyage." This film described the cutting of a victory ship in two, splicing a section in the middle to make a Great Lakes ore vessel. Job was done by Bethlehem Steel Co. for the Cleveland Cliffs Steam Ship Co. The vessel was towed from Baltimore, Md., Bethlehem Steel Yards, around the tip of Florida, up the Mississippi River, through the Chicago Canal into the Great Lakes. It required only 170 days from the start of the work until delivery to the Cleveland Cliffs Steam Ship Co.

At the technical meeting, the members and guests heard an illustrated talk given by Christian Arne on the "Hortonsphere," built by the Chicago Bridge and Iron Co. at West Milton, N. Y., for the testing of atomic power engines. Mr. Arne described the design and field erection problems encountered in completing the Sphere and quoted some very interesting statistics. The Sphere is 225 ft in diameter, 1-in. thick plate is supported by a single foundation and has 26 columns, 74 ft high, located at about the equator of the sphere. There are approximately 5 miles of welded seams in the shell, of which 15,000 ft were submerged-arc automatic welded and 11,000 hand welded. The entrances to the sphere are smaller spheres and incorporate air lock. All welds were radiographed 100%, then a soap bubble test at 2 psi internal pressure, and then 20 lb.

Welding Pure Titanium

Boston, Mass.—A technical paper on the "Welding of Commercially Pure Titanium," illustrated with some very effective slides, was presented by Carl E. Hartbower, AWS, Chief, Welding Section, Watertown Arsenal, at the October 14th dinner meeting of the *Boston* Section, held at the Westinghouse Auditorium. The paper described the study of the chemical composition, microstructure and mechanical properties of various titanium alloy filler materials when deposited in commercially pure-base metal by inert-gas-shielded tungsten-arc process.

Lt. Walter Flaherty, alias Prof. Bruno DiAngelo, of the Watertown Police Department, entertained the guests before the technical meeting.

Low-Hydrogen Electrodes

Buffalo, N. Y.—Seventy-two members and guests of the *Niagara Frontier* Section were present at dinner on September 24th at the Hotel Sheraton. An attendance of 90 at the technical session heard Dr. D. C. Smith, AWS, of the Harnischfeger Corp., give an excellent address on the subject "Low-Hydrogen Electrodes and Their Use in Industry."

Welding Aluminum

Chicago, Ill.—The September 18th dinner meeting of the *Chicago* Section, held in Peoples Gas Light & Coke Co., Auditorium, with an attendance of 69, was addressed by Charles Bruno, AWS, Chief Welding Engineer, Reynolds Metals Co., on the ever-popular subject "Welding Aluminum."

Hard Facing

Cincinnati, Ohio.—The first regular meeting of the *Cincinnati* Section for the 1953–54 Season was held on Tuesday, September 22nd, at the Engineers Club. The subject of interest to all welding men—Hard Facing Applications and Related Alloys—was presented by a speaker well qualified to discuss the practical as well as the technical aspects of the subject, Harry V. Kough, AWS, National Service Engineer for Coast Metals Co. in Little Ferry, N. J.

Heavy Sections

Cleveland, Ohio.—More than 100 members and guests attended the *Cleveland* Section's first meeting of the 1953–54 season on October 14th. Among those

Allen P. Stern (standing) introduces 17 out-of-town guests he brought to the Cleveland October meeting

attending were 17 guests of Allen Stern, President of Colonial Iron Works and Second Vice-Chairman of the Section. Chairman Lew Gilbert, Executive Editor of *Industry and Welding*, introduced the Section's new officers and committee chairmen.

The principal speaker of the evening was N. C. Jessen, AWS, of the Barberton Works, Babcock and Wilcox Co., who spoke on "Welding Heavy Sections of Carbon-Steel Plate." Outlining the two major applications for heavy welded plate machinery frames and pressure vessels, Mr. Jessen elaborated on those major headings, using slides and a "style" of presentation which made his discussion easily understandable. The speaker pointed out that the operator must recognize the mechanical properties of the steel to be welded and that adequate welding procedures should be utilized. Manual and submerged arc processes used for welding this grade of steel were discussed along with precautions which should be taken when using them.

Coffee speaker for the evening was a member of Alcoholics Anonymous whose topic was "Who Me?"

Welding Metallurgy

Columbus, Ohio.—Robert W. Bennett, AWS, Chief Metallurgical Engineer of the American Locomotive Co.'s Dunkirk, plant, spoke at the dinner meeting of the *Columbus* Section, held on October 9th at the Riverside Restaurant. Mr. Bennett's talk entitled "A Metallurgical Approach to Welding Fabrication Problems" concerned the application of laboratory findings to the welding of large heat exchangers and pressure vessels intended for low-temperature work. The laboratory work included metallic, submerged, and inert-gas shielded-arc welding.

John H. Blankenbuehler, District 4 Vice-President, visited the Columbus Section accompanied by Chairman Glynn Williams and Secretary W. H. Hobart, Jr., of the Dayton Section.

Shaping of Steel

Dallas, Tex.—J. M. Zuber, Vice-President and Trust Officer for the Republic National Bank, Dallas, was the speaker at the September 23rd meeting of the *Dallas* Section held in the Venus Restaurant. His subject, "Planning Your Personal Affairs," went over big.

Before-the-meeting feature was the showing of an excellent film entitled "Making and Shaping of Steel" through the courtesy of the United States Steel Corp.

Dayton Meetings

Dayton, Ohio.—The following regular monthly meetings of the *Dayton* Section will be held at 8 P.M. in the Dayton Engineers Club, 112 E. Monument Ave., unless otherwise announced:

January 12th—"Mission of Wright Air Development Center." Ladies' Night—Special film and talk. Dinner at 6:30 P.M. Meeting 8:00 P.M.

February 9th—"Factors in the Selection of Welding Processes." Speaker to be announced.

March 9th—"High Production Applications of Resistance Welders." Clarence Schultheis, Frigidaire Division, GMC, Dayton, Ohio.

April 13th—"Tooling for Automatic Welding." Anthony K. Pandjiris, AWS, Pandjiris Welding Co., St. Louis, Mo.

May 11th—Plant Visitation. To be announced.

June 8th—Annual Picnic.

Plant Tour

Dayton, Ohio.—On October 13th, 80 members of the *Dayton* Section made a tour of the plant of the Monarch Machine Tool Co. in Sidney, Ohio.

Welding Machine

Decatur, Ill.—G. K. Willecke, AWS, of the Miller Electric Manufacturing Co., Appleton, Wis., presented an excellent discussion on the subject "Rectifier-Type D-C Welding Machine" at the October 13th meeting of the *Sangamon Valley* Section held at the Hotel Charles, Decatur, Ill.

Coffee speaker was Paul Swarm who gave an excellent talk on "Music for Enjoyment."

Fixtures for Automatic Welding

Denver, Colo.—Members of the *Colorado* Section met on October 13th at a dinner meeting held in the Festival Room of the Oxford Hotel where they heard a most important paper on the subject "Fixtures for Automatic Welding" as presented by Ralph A. Trentham, General Manager of the Reed Engineering Co., Carthage, Mo.

The after-dinner feature was a talk by Norman O. Pierce, Mountain States Tel. & Tel. Co. on the subject "Teletopics."

Welding Aluminum

Des Moines, Iowa.—Charles Bruno, AWS, of Reynolds Metals Co., Louisville, Ky., gave a most excellent talk on "Welding Aluminum" before an audience of *Iowa* Section members and guests at a dinner meeting held on October 15th at the New Pastime Restaurant.

Following the favorite smörgåsbord style dinner, Mr. Bruno began his speech with illustrations of the Common Alloy Series of Aluminum and the Heat-Treatable Alloy Series. The former series are nearly all weldable by one process or another and even solderable if proper precautions are taken. The latter series being copper and magnesium based on weldable only by the resistance processes. Only within the past six months are the new inert-gas-shielded arc guns making the fusion welding of aluminum possible to any great degree.

One of the most important facts to remember in welding aluminum is to remove the surface oxides present on all alloys of aluminum. The oxide is as clear as glass, melts at 5300° and becomes rubbery at 600 to 700°, all of which makes its removal difficult, and under an arc, it tends to increase. Flux must be used at all times while welding since the oxidation progresses so rapidly. Once melted, the aluminum reverts to a cast structure which is but one-half as strong as the wrought structure; therefore, the quicker and narrower an aluminum weld is made, the stronger the joint will be. By using the percussion method of welding, a cast structure is obtained that is only half of $^{1}/_{10,000}$ in. thicker.

Metallizing

Detroit, Mich.—One hundred and nine members and guests of the *Detroit* Section were present on October 9th to hear Knowles B. Smith, AWS, Vice-President and General Manager of the Dix Engineer-

ing Co., Inc., give an extemporaneous talk on the subject "Metallizing and Its Industrial Application." A 30-min film on the same subject described the process and showed in detail its practical use, and afforded everyone an opportunity to become better acquainted with the subject.

Forty-four members were present at the dinner to hear Capt. Gerald Montgomery of the Public Relations Division, Detroit Fire Department, give a significant talk on "Taking the Heat Out of Welding."

Silver Brazing

Erie, Pa.—A comprehensive talk on the subject "Fundamentals of Silver Brazing" was presented by Stanley Cross, AWS, of the American Platinum Works at the October 21st dinner meeting of the *Northwestern Pennsylvania* Section held at Priscilla's Cape Cod Kitchen.

A 16-mm film entitled "High Powder" was shown before the meeting.

Sigma Welding

Grand Rapids, Mich.—New methods and applications were covered by T. W. Efelgroth, Regional Service Engineer, Linde Air Products Co., in a semitechnical talk on the subject "Sigma Welding—New Inert Process," presented before the September 28th dinner meeting of the *Western Michigan* Section held at the Varsity Grille in Grand Rapids. Surprise coffee speaker was Doug LaDue, AWS, an Engineer at AMI, Inc., who told about his company and its manufacturing operations.

Weld Design

Kansas City, Mo.—The October meeting of the *Kansas City* Section was held on October 8th in Fred Harvey's Pine Room with an attendance of over 39 at dinner and over 50 at the technical meeting.

Tom Nicholl, AWS, District Manager of the Lincoln Electric Co., gave a very interesting talk entitled "Weld Design—Economy in Welding." He discussed the engineering approach to the proper choice of available material and the properties of the material that are all too frequently overlooked. He also discussed methods of reducing cost both in the final product and in the cost of welding. Mr. Nicholl pointed out that it is very important that every designer know when to weld and when not to weld.

Copper Furnace Brazing

Long Beach, Calif.—An excellent extemporaneous talk on "Controlled Atmosphere Copper Furnace Brazing" was given by A. M. Thompson, AWS, of the Fabriform Metal Products Co. at the September 18th dinner meeting of the *Long Beach* Section held at Miller's Restaurant. Mr.

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Thompson's discussion was illustrated with slides and motion pictures.

Electronic Tubes

Milwaukee, Wis.—The regular monthly meeting of the *Milwaukee* Section for September was held on the 18th at the Ambassador Hotel with approximately 60 members and guests in attendance.

The after-dinner program arranged by Director John Linnehan featured an excellent presentation by Hal Goodnough, Milwaukee Braves Public Relations Director on the subject "Big League Baseball." He related many of the success stories of big league ball players, as well as an array of amusing anecdotes pertaining to the game, stressing the point that anyone interested in playing ball has an equal chance to advance to the majors regardless of race, creed or color. Success depends entirely upon skill.

The technical address on the subject "Thyratron and Ignitron Tubes as Used in Industry" was arranged by Vice-Chairman Don Wilson and presented by Stuart Rockafellow, AWS, Vice-President and Chief Engineer of Robotron Corp. Mr. Rockafellow handled this highly technical subject in a down-to-earth manner using a demonstration board to explain rather simply the use of electronic tubes in resistance welding controls. He explained differences between vacuum and gas-filled tubes, simple timing circuits, sequence circuits, phase shift circuits, operation of ignitrons and up-down slope controls. Literature was passed out summarizing in a simple manner all of the valuable data and information discussed.

Mr. Rockafellow holds several patents on welding control circuits, as well as airplane control systems, blind landing and glide path.

Milwaukee Meeting Dates

Milwaukee, Wis.—The regular meeting dates of the *Milwaukee* Section for the remainder of the season as well as speakers and subjects are given below:

Friday, Dec. 18, 1953
Speaker: A. K. Pandjiris, AWS.
Subject: "Positioners, Jigs and Fixtures for Semi- or Full-Automatic Submerged Arc Welding."

Friday, Jan. 22, 1954
Speaker: G. K. Willecke, AWS.
Subject: "An Evaluation of the Selenium Rectifier for Welding Purposes."

Friday, Feb. 26, 1954
Speaker: William Poehlman, AWS
Subject: "Structural Steel Fabrication."

Friday, Apr. 23, 1954
Speaker: Charles Hautau.
Subject: "Methods of Automation."

Saturday, May 22, 1954–May Party.

Soldering

Milwaukee, Wis.—The October meeting of the *Milwaukee* Section was held on the 16th at the Ambassador Hotel with approximately 50 members and guests in attendance.

After dinner, the subject "Television in Milwaukee" was ably presented by Kal Ross, a Director substituting for Lou Poller, General Manager of WCAN-TV, a new UHF station in the Milwaukee area. Kal Ross has been loaned to WCAN-TV by CBS of New York to help in programming. The difference between UHF and VHF was discussed as well as "inside information" regarding programming.

Technical speaker was R. M. MacIntosh, Supervisor of Chemical Department for the Tin Research Institute, Inc., of Columbus, Ohio, who spoke on the subject "Soldering." Mr. MacIntosh is a recognized authority on the subject and is a graduate of the Royal Technical College, Glasgow, Scotland, and Brooklyn Polytechnic Institute. He has been engaged in metallurgical research since 1926.

Mr. MacIntosh pointed out the factors involved in the selection of the soldering process over other methods of joining metals. These factors included the influence of the metals to be joined, properties of solders and soldered joints, joint preparation, selection of the correct solder alloy for specific metals and alloys, assembly of the parts to be joined, flux selection, heating methods used and post-heating procedures. Special techniques for the hard-to-solder metals were discussed in detail and illustrated with actual application photographs.

Educational Course

Milwaukee, Wis.—The 1954 Educational Course sponsored by the *Milwaukee* Section will feature three outstanding speakers—Second Vice-President John Chyle, AWS, of the A. O. Smith Corp., who will cover the subject "Arc Welding"; Mark Hippe, AWS, of Linde Air Products Co., who will lecture on "Gas Welding and Cutting"; and Art Kugler, AWS, of Air Reduction Sales Co. who will cover "Inert-Gas Welding." The fourth meeting in the series will be a plant tour. The meetings will be held at Marquette University, Jan. 11th, 18th and 25th, with the plant tour scheduled for February 1st.

Get Acquainted Meeting

Minneapolis, Minn.—The activities of the *Northwest* Section got under way for the year 1953–54 with an executive committee meeting on September 10th. This was presided over by Chairman Hanson and business details for the coming year were discussed. The first Section meeting was held in the Covered Wagon on Monday, September 14th. This was an annual "get-acquainted" meeting at which Section activities for the coming year were announced and committee appointments made and members introduced. Two colored movies furnished by the Allegheny Ludlum Steel Corp. were shown. The host for the happy half hour preceding dinner was the Paper Calmenson Co. of St. Paul who annually sponsor the opening meeting.

The Chairman announced the following committee appointments:

MEMBERSHIP: Marshall Ford, *Chairman*, aided by Merton Collum, Roger Griffis, Sverre Olson, William T. Morin and Emil Schroeder.

PROGRAM COMMITTEE: W. E. Coleman, *Chairman*.

PUBLICITY COMMITTEE: Roy Spaulding and Clarence Reinecke, *Co-Chairmen*.

EDUCATIONAL COMMITTEE: C. M. Clogston and Roy Williams.

BUILDING CODE COMMITTEE: Ted Kenny.

TECHNICAL REPRESENTATIVES: F. W. Scott and Mr. McDonald.

Rigid Frames

New York, N. Y.—Bruce G. Johnston, Professor of Structural Engineering, Department of Civil Engineering, University of Michigan, was the guest speaker at the October 13th meeting of the *New York* Section. His excellent subject, "Industrial Building Frames Under Atomic Blast," was well received. The paper reported the results of dynamic analyses of

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simple steel frame industrial buildings under assumed conditions of exposure to atomic bomb explosion and discussed modifications that might serve to increase the resistance of buildings to atomic blast loads.

The program was preceded by dinner at Schwartz's Restaurant, 54 Broad St., New York City, where the meetings are regularly held.

Welding of Nickel

Oak Ridge, Tenn.—K. M. Spicer, AWS, Welding Engineer, The International Nickel Co., New York, presented an excellent semitechnical address on the subject, "Welding of Nickel and High Nickel Alloys" at the September 21st dinner meeting of the *Northeast Tennessee* Section held at the Knights of Columbus Hall in Oak Ridge.

Welding of Pressure Vessels

Oak Ridge, Tenn.—R. E. Lorentz, AWS, Division Metallurgist for the Combustion Engineering Co., Chattanooga, Tenn., was the guest speaker at the October 16th dinner meeting of the *Northeast Tennessee* Section held at the S & W Cafeteria in Knoxville. His subject was "The Welding of Pressure Vessels."

Shipbuilding Industry

Pascagoula, Miss.—At the October 7th meeting of the *Pascagoula* Section, Robert H. Macy, AWS, Technical Assistant to the President of Ingall's Shipbuilding Corp., delivered an excellent speech on "Diversification in the Welded Shipbuilding Industry."

Mr. Macy's speech covered the problems of the shipbuilder in trying to diversify his operations to the extent that he could maintain full employment during the lulls with which we are all familiar. One interesting point brought out, and subsequently discussed, was that in order to balance your trades and utilize your facilities to the fullest extent, you must get into the heavy complex machine industries. Mr. Macy pointed out that competition was keen in this field and that a yard could not stop production of equipment that had gained recognition and swing to shipbuilding when ships were in demand.

At the conclusion of his talk, Mr. Macy and members discussed the various fields open to a concern engaged primarily in the construction of welded ships. Among the items discussed were pressure vessels, Diesel locomotives, house trailers, and prefabricated houses. Mr. Macy pointed out the difficulties to be overcome in the production of these items such as restricted and distant markets, necessity for assembly line methods to meet competition, and supply of raw materials.

Maintenance Welding

Peoria, Ill.—The regular monthly dinner meeting of the *Central Illinois* Section for October was held on the 21st at the Sazarac. Fifty-seven members and guests heard an extemporaneous discussion on the subject Maintenance Welding—semi- and full-automatic rebuilding and repairs of steel mill and brazing of heavy cast-iron sections, as given by Cares C. Keyser, AWS, Welding Engineer of the Bethlehem Steel Co. Mr. Keyser's discussion was exceptionally well received. Technical Chairman was A. A. Wald, Superintendent of Maintenance, Caterpillar Tractor Co., Peoria, Ill.

Rigid Frames

Philadelphia, Pa.—The *Philadelphia* Section met on October 19th at the Engineers Club. The Section was indeed honored to have for their guest speaker of the evening, Martin P. Korn, AWS, pioneer designer and noted consultant, who spoke on welding of rigid frames. Mr. Korn's subject was not only a most timely one, but was of such keen interest that a large delegation of young Civil Engineers and students from Drexel Institute and other local Universities were present to hear him. Mr. Korn's speech was accompanied by a number of most interesting slides showing rigid frames now used in permanent construction from one side of our country to the other, to say nothing of a number of these designs being used in foreign countries.

Mr. Korn, M.ASCE, is a Consulting Engineer with Giffels & Vallet, Inc., of Detroit. Some of his work is represented in structures all over the country. He is a member of the AWS committee on Building Codes, for which he initiated that portion pertaining to rigid frames. Mr. Korn has published numerous articles on design and is the author of the well-received book *Steel Ribs in the Sky*.

Buildings of Tomorrow

Phoenix, Ariz.—The regular monthly meeting of the *Arizona* Section was held on October 21st at the Hotel Westward Ho with approximately 40 members and guests present. Following dinner, a most interesting talk was given by Richard E. Drover of the Phoenix architectural firm of Weaver and Drover, on the subject "Buildings of Tomorrow." Mr. Drover pointed out how the trend is toward lightweight walls instead of the old masonry type and how more effective use of steel is being achieved through the use of welding by placing the steel where it is needed and eliminating surplus weight at lowly stressed points. Mr. Drover is practical, as well as very artistic, thus making his presentation well received and giving much food for thought.

The second speaker of the evening was A. F. Fenalson, AWS, Welding Procedures Superintendent for Consolidated Western Steel Plants, who showed colored slides of some of his company's construction projects and pointed out problems and solutions encountered. Mr. Fenalson's background and broad experience made possible a most interesting presentation.

A very clever and interesting film "Designing for Structural Arc Welding" was also shown through the courtesy of the Lincoln Electric Co.

All present agreed that the meeting was highly successful and the Section's thanks were extended to those who made it possible by the Chairman, Charles Fogwell.

Plant Visitation

Pittsburgh, Pa.—The *Pittsburgh* Section visited the plant of the National Tube Division of the United States Steel Corp. at McKeesport, Pa., where the members were given an opportunity to witness the manufacture of 26 to 36 in. diam, electric welded pipe, intended for gas transportation. The manufacture was traced to the sheets arriving from the plate mill. These sheets or plate are of the required dimension and steel grade to manufacture electric welded pipe of the diameter, thickness and length specified in the customers order. The plate is sheared so that the finished pipe will be at right angles with a longitu-

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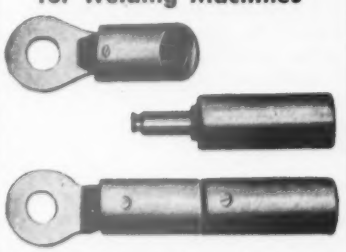

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dinal pipe access. Each operation was shown including the edge forming of the plates, the bend into a U and into an O and the welding operations by the submerged arc process, including the outside welding and inside welding. Inspection of pipe welds were covered as well as the expanding operation of the finished diameter and wall thickness.

Automotive Welding

Saginaw, Mich.—The second meeting of the season of the *Saginaw Valley* Section, held on October 8th, attracted 92 members and guests to hear Stuart M. Spice, AWS, Welding Engineer of the Buick Motor Division, speak on "Welding Process Control in Automobile Manufacture." Prior to the address, a movie on Caribou hunting was shown, an excellent short on the life of the North Canadian Indians.

Mr. Spice has been Welding Engineer at Buick for the past 15 years, and has been responsible for the development and application of various welding processes to the manufacture of automobiles. His talk covered the application of submerged arc, inert arc, stick electrode and resistance welding to the fabrication of component parts of the automobile. Slide illustrations showed typical job setups for individual assemblies involved.

Plant Tour

St. Louis, Mo.—A tour of the Lincoln-Mercury Plant in Robertson, Mo., was made by 450 members and guests of the *St. Louis* Section on September 11th. This plant tour was very well attended and seemed to be of great interest to all those present. All the operations in assembling an automobile were observed, with the exception of engine assembly and some of the painting operations. Spot welding of body parts was very interesting. Those who attended were greatly impressed with the efficiency of the assembly operations. It appeared that every motion made by each employee was effective. The complexity of scheduling and routing problems was also noted, as well as the effective means of overcoming them.

It appeared that many parts in the automobile had to go into a particular unit, because frames were numbered as well as engines, and painted parts had to match. All parts seemed to get to the right place at the right time.

All in all, the efficiency of the American production line technique was very much in evidence on this tour.

Selenium Rectifiers

Seattle, Wash.—The *Puget Sound* Section held its regular monthly dinner meeting on September 10th at the Engineers Club in Seattle. Gary Willecke, AWS, of the Miller Electric Manufacturing Co. gave an excellent extemporaneous talk on the subject "Selenium Oxide Rectifiers in Today's Arc Welding" which was illustrated with slides.

Welding Procedures

Seattle, Wash.—Another excellent extemporaneous discussion was given at the October 8th dinner meeting of the *Puget Sound* Section by Elwin Messer of Todd Ship Yards on the subject "Present Day Welding Procedures." A tour was also made through the Todd Shipyards.

Inspection Trip

South Bend, Ind.—Walter Wille, AWS of the Oliver Corp. made arrangements for members of the *Michiana* Section to take a trip on October 15th through the South Bend Plant 1 where agricultural tilling equipment and 155-mm shell forgings are made. Welding on these farm implements becomes quite a problem, for the biggest share of them are made from cast-iron or higher carbon steels (0.45 to 1.00%). A most interesting feature is the manufacture of harrow points on a reverse-acting spot welder. The shell forging line is very dependent on welding, for die life is relatively short and the punches are repaired by hard facing and grinding back to size. Thanks were extended to Mr. Wille and his crew of guides for a very interesting tour.

Aircomatic Welding

South Bend, Ind.—The *Michiana* Section gave H. C. Opie of the Air Reduction Co. a busy evening answering questions on "Aircomatic Welding" when he spoke on the subject for the September 17th meeting. Most of the interest was centered on the welding of steel, which is the newest and least developed of the materials to which this process is applied. A movie showing applications for this type of welding preceded the discussion. About 30 members and guests attended the opening session of the new season.

Welding Distortion and Control

Syracuse, N. Y.—Approximately 90 members and guests were present at the October 14th meeting of the *Syracuse* Section. The technical speaker was J. S. Roscoe, AWS, Executive Vice-President of the Lincoln Electric Co., who spoke on "Welding Distortion and Its Control."

Mr. Roscoe, who was formerly the Lincoln representative in the Central New York area, renewed old acquaintenances with many of the members. A special reunion luncheon was held with Mr. Roscoe prior to the dinner meeting.

Some of the technical highlights of Mr. Roscoe's talk brought out the following facts:

Technical Speaker J. S. Roscoe

Metals expand when heated and contract when cooled. In the arc welding process the arc heats the metals being welded, therefore expansion and contraction are bound to occur. When this expansion and contraction are not controlled, distortion is likely to result.

Three simple rules can be followed which will aid materially in the prevention and control of distortion. In many cases the application of a single rule will be sufficient. In others, a combination of the rules may be required. Rule I: Reduce the effective shrinkage force. Rule II: Make shrinkage forces work to reduce distortion. Rule III: Balance shrinkage forces with other forces.

Program Schedule

Syracuse, N. Y.—Meetings of the *Syracuse* Section are held in the Hiawatha Room, Onondaga Hotel, and start at 8 P.M. Dinner starts at 6:30 P.M. The following is a schedule of the 1954 meetings:

Jan. 13, 1954
Subject: "Jigs and Fixtures for Arc Welding."
Speaker: A. K. Pandjiris, AWS, President, Pandjiris Weldment Co., St. Louis, Mo.

Feb. 10, 1954
Subject: "Welded Steel Structures."
Speaker: Van Rensselaer P. Saxe, AWS, Consulting Engineer, Baltimore, Md.

Mar. 10, 1954
Subject: "Applications for Submerged Arc Welding."
Speaker: H. J. Bischsel, AWS, Welding Engineer, Westinghouse Electric Corp., Buffalo, N. Y.

Apr. 14, 1954
Subject: "Bronze Electrodes and Filler Materials."

Speaker: F. Emery Garriott, AWS, Manager, Weldrod and Wire Dept., Ampco Metal, Inc., Milwaukee, Wis.
May 12, 1954—Annual Dinner Meeting.

Welding, Its Application to Rockets

Tucson, Ariz.—The *Tucson* Section opened its Fall and Winter meetings on September 22nd at The Outpost on Highway 84, Tucson, with 30 members present. The meeting was highlighted by a guest speaker from the Aerojet General Corp. of Azusa, Calif., Francis H. Stevenson, AWS, who spoke on the timely subject of "Welding, Its Application to Rockets." Mr. Stevenson explained the processes used in welding titanium and stainless steel and the problems encountered in welding these metals properly. He had many samples to pass around to show the finished welds in titanium and stainless. After a long and interesting discussion, Mr. Stevenson showed a sound movie, The Aerobee, depicting the preparation and the flight of a rocket ship.

The coffee speaker was Vernon McCracken, Manager of the Employment Security Commission, Tucson office. Mr. McCracken spoke on the employment compensation and its relation to both the employee and the employer.

LIST OF NEW MEMBERS

Effective September 30, 1953

Membership Classification

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ARIZONA

Cook, A. V. (C)
Lynn, Joseph E. (C)
Mooney, Edward L. (C)
Spangler, Melvin E. (C)
Walker, Don (C)

BOSTON

Wood, Thomas M. (B)

CHICAGO

Clark, James G. (B)
Voss, Frederick J. (A)
Pope, Bruce A. (B)
Weigert, Karl Max (C)

CINCINNATI

Hitch, Jim (C)

CLEVELAND

Cheeseman, Evans W. (B)
Coates, George R. (C)
Gordon, Mack (B)
Green, Hart E. (B)
Karoly, Otto (B)
Mattoon, Robert A. (C)
Miller, Kenneth J. (B)
Pagenkopf, Robert C. (C)
Rusnak, William A. (B)
Whitney, Clifford J. (B)

COLUMBUS

Bayne, Fred R. (C)
Buehler, Lawrence (C)
Clair, Stephen S. Jr. (B)
Howell, G. H. (C)
McLain, John R. (C)
Mishler, Herbert W. (C)
Speer, Paul E. (C)

DALLAS

Ezekiel, Freddy J. (D)
Miller, Robert F. (C)

DAYTON

Kahkola, Wilho R. (B)

DETROIT

Cudini, R. G. (B)
Hinz, T. A. (A)
Howell, David S. (B)
Lentz, Leonard A. (B)
Sullivan, Josh M. (C)
Williamson, Walter (B)

HOUSTON

Biziak, J. A. (B)
Bryant, Harvy (B)
Massa, William (C)
McKinnon, T. J. (B)
Poarch, Hoot (B)

KANSAS CITY

McDowell, T. O. (C)

LEHIGH VALLEY

Knotts, Victor A. (C)

LONG BEACH

Harrison, Robert B. (B)
Walter, William J. (C)

LOUISVILLE

Collins, W. Melvin (C)
Darling, Jacob Byron (D)
Davis, William C. (B)

MAHONING VALLEY

Livingston, Henry J. (C)
McDermott, L. B. Sr. (C)

MILWAUKEE

Sell, Gerhardt (C)

NEW JERSEY

Bates, Douglas P. (B)
Bising, James M. (B)
Enzman, August J. (C)
Erdely, Frank (C)
Finigan, Robert J. (B)
Hoffman, Henry H. (B)
Joheso, John E. (C)
McCaulley, Sam (C)
Sachs, Frank L. (C)

NIAGARA FRONTIER

Ciresi, Joseph J. (B)
Dempsey, Charles W. (C)

NORTHEAST TENNESSEE

Erbentruth, Frank (C)
Houchins, Robert V. (B)

NORTHWEST

Hanson, L. O. (C)
MacNabb, A. W. (C)
Reinhardt, Paige (A)
Wojcik, Walter J. (C)

NORTHWESTERN PENNSYLVANIA

Spencer, Roy W. (C)
Trombetta, Enrico A. (C)

PHILADELPHIA

Bunio, John J. (B)
D'Amelio, Joseph H. Jr. (B)
Davaney, L. F. (B)
Freyberger, Donald L. (B)
Pukas, Theodore J. (B)
Swoyer, John H. (B)

PITTSBURGH

King, Milton S. (C)

PORTLAND

Kissler, Laurence H. (B)
Quimby, J. M. (B)
Rogers, Laurence B. (B)

PUGET SOUND

Cornwall, E. P. (C)
Kinnaird, Eric (B)
MacDonald, Hugh T. (C)

ROCHESTER

Masterson, Donald P. (B)

SAGINAW VALLEY

Buerker, Arthur (B)
Rosenbaum, Richard E. (C)
Westendorf, Elmer L. (C)

SAN FRANCISCO

Wilson, A. E. (B)

SANGAMON VALLEY

Lacestee, Peter (B)

SYRACUSE

Edlund, Carl A. (C)
Johnson, William H. Jr. (C)
Kurtz, Earl A. (C)
Marano, Michael (C)
Mills, Loring E. (C)
Robinson, Osco H. (C)

TUCSON

Barnier, A. W. (C)
Walzak, Edward (C)

TULSA

Badeen, Mike (B)
Veal, Leo D. (B)

NOT IN SECTIONS

Arbuthnot, W. R. (C)
Chambers, Edward A. (B)
Mookerjee, M. K. (B)
Sawyer, Russ Edmund (C)
Thelinge, J. (C)
Wahlgreen, Hans (C)

Members Reclassified

During the Month of October

CLEVELAND

Plummer, Fred L. (B to F)
Romance, Wasil (D to C)

HARTFORD

Kirkley, George W. (C to B)
Harrington, Blaine G. Jr., (C to B)

NEW JERSEY

Abbott, L. E. (B to A)

NIAGARA FRONTIER

Swan, David (C to B)

NOT IN SECTIONS

Frala, Robert E. (D to C)

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,654,014—Method of Inert-Arc Welding of Stainless Tubing—Walter S. Schaefer, Euclid, Ohio, assignor to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

This patented method is for welding a longitudinal seam in metallic tube blanks and it comprises the steps of injecting inert gas into the interior of the tube at one portion thereof, confining the inert gas in that portion of the tube blank, and striking an arc against the seam at said portion of the blank. Relative motion is produced between the arc and the blank and the inert gas is injected at successive different portions of the blank and a magnetic field is passed through the arc transversely thereto and to the direction of motion of the blank. The magnetic field is of such polarity in relation to the polarity of the arc current so as to apply a force to the arc in a direction opposite to the relative direction of motion of the blank and such field is of insufficient strength to hold the arc vertical but sufficient to hold the arc substantially erect with a slight arc trail. Thus the arc is electromagnetically deflected in a direction opposite to the relative direction of motion of the blank so that the arc trail angle is diminished.

2,654,015—Method and Apparatus for Arc Welding Using a Plurality of Electrodes—George G. Landis, South Euclid, and Norman J. Hoenie, Cleveland Heights, Ohio, assignors to The Lincoln Electric Co., Cleveland, Ohio a corporation of Ohio.

In this patented method, a plurality of electrodes are simultaneously fed to a metal workpiece in spaced relation to each other and the terminal portions of all of such electrodes adjacent the arc ends thereof have the same welding voltage supplied thereto. The current produced is effective to cause substantially instantaneous fusion of the electrode end of any one of the electrodes so that whenever the end of any one of the electrodes comes into contact with the workpiece the electrodes are electrically connected in the welding circuit in parallel relation to each other.

2,654,019—High-Frequency Induction-Heating Apparatus—Alfred C. Body, Cleveland, Ohio, assignor to The Ohio Crankshaft Co., Cleveland, Ohio, a corporation of Ohio.

Body's patent is on a method of heating the opposite edges of a C-shaped metallic tube to welding temperature and includes the steps of inducing from both sides of the edges currents to flow along the edges in the same direction. Other currents are induced from both sides of the tube to flow in the opposite direction remote from such adjacent edges but with said second induced currents being circumferentially spaced from the currents induced to flow on the inside of the tube.

2,654,129—Method of and Apparatus for Welding—Edward B. Neff, Shaker Heights, Ohio, assignor to Erico Products, Inc., Cleveland, Ohio, a corporation of Ohio.

Apparatus for use in cast welding is covered in the patent and includes a mold having a mold cavity in one face adapted to be presented to a surface of one member to be welded, which cavity also receives a second member to be welded with a portion of the second member extending laterally therefrom in contact with the surface of the first member. A support frame is provided for the mold and it has pressure means for engaging the second member to press it forcibly against the first member while other means mount the mold on the frame for movement relative to the pressure means to permit the mold to bear against the second member less forcibly than the pressure means.

2,654,143—Method of Making Welded Blade Structures—Elmer D. Hoesch, West Allis, and Robert G. Matters, Milwaukee, Wis., assignors to Allis-Chalmers Manufacturing Co., Milwaukee, Wis., a corporation of Delaware.

This patent relates to the making of a bladed element for turbines and the like. First a circumferential row of blades is placed around a rotor disk with the base portions of the blades and the rim portion of the disk cooperating to define an annular weld receiving contour. Liquid retaining means are provided in cooperable relation to the blades to enclose an area to receive and retain a slurry in engagement with the blades except in a zone about the weld receivable contour. A slurry of solidifiable material is placed in the enclosed area so that upon solidification of such material it seizes and holds the blades in position. Thereafter a weld material is applied to the weld receivable contour and thereafter the solidifiable material is removed after the weld metal freezes.

2,655,206—Cutting Torch Tip, Including High and Low Velocity Preheat Passages—Francis J. Eichelman, Brookfield, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a Corporation of Delaware.

This novel torch tip includes a tip body having a central discharge orifice means for oxidizing gas and at least two discharge orifice means for the combustible gas mixture in the end of a tip body. A single mixing means is provided for producing a combustible gas mixture in the end of the torch tip and additional separate passages are provided for oxidizing gas and fuel gas and these passages communicate with the mixing means and a passage means provided in the torch tip for delivering the combustible gas mixture to at least one of its discharge orifice means at high velocity and to one other of the discharge orifice means at substantially lower velocity.

2,655,580—Safety Switch for Welding Holders—Andrew T. Tetrault, Indian Orchard, Mass.

This patent relates to a special spring-actuated, normally open switch for use on a welding electrode holder.

2,655,583—Welding Electrode—John C. Souter, West Newbury, Mass., assignor to Western Electric Co., Inc., New York., N. Y., a corporation of New York.

Souter's patented electrode comprises a member having a circular aperture intersecting a surface therein from one surface thereof, and an element is received in the aperture for rocking movement therein. Contacts are mounted at spaced portions of the element outside the aperture to move with the element to engage spaced portions of an article to be welded.

2,655,585—Welding Machine—Leo Braun, Montreal, Quebec, Canada, assignor to Dominion Bridge Co. Ltd., Montreal, Quebec, Canada.

This new type of a welding machine includes an elongate beam which is positioned for movement in a longitudinal direction in a horizontal plane. Other means are provided for raising and lowering the beam and a welding head assembly is pivotally connected to one end of the beam to provide a vertical axis about which the welding head assembly is swingable to different operating positions. Other means control the position of the welding head with relation to its positioning beam.

2,655,586—Multiple Electrode Polyphase Arc Welding—Norman G. Schreiner, Philadelphia, Pa., and Edwin A. Clapp, Niagara Falls, N. Y., assignors, by mesne assignments, to Union Carbide and Carbon Corp., a corporation of New York.

This electric arc welding method comprises maintaining at least two metal fusing and metal depositing electric arcs in tandem in a common weld zone on the work and such arcs are energized from a single three-phase power source through leads containing variable reactance means. Weld metal is continuously independently supplied to each arc as metal is fused thereby and relative movement between the arcs and the work is coordinated with the rate of fusion. The voltages of each arc are independently controlled to maintain such arc voltage at a predetermined substantially constant value. By varying the reactance means a phase angle of less than 140° and more than 60° is maintained between the arc currents to vibrate at least the trailing arc with a predominantly leading component in the direction of the weld.

2,655,656—Vented Face Shield for Welders—William C. Moeller, Kansas City, Mo., assignor to Parmelee Plastics Co., Kansas City, Mo., a corporation of Missouri.

The patent face protector includes an elongated, longitudinally arcuate shield of transparent material having a plurality of vent openings therein. A foraminous panel is mounted on the normally innermost face of the shield and covers the openings and an outwardly and downwardly extending deflecting louver is provided on each opening on the normally outermost face of the shield.

2,655,988—Gas Torch Tip Having Protective Terminal Shoe—Daniel A. Marra, Cheswick, Pa.

Marra's patent relates to a special blow-torch tip wherein an elongate outer body is provided which has a perforate terminal protecting shoe formed of a relatively hard, highly refractory sintered carbide having high strength and durability when exposed to welding temperatures in the presence of oxygen.

2,656,445—Welding Machine and Control and Actuating Mechanism—Ernest J. Svenson, Rockford, Ill., assignor to Odin Corp., Chicago, Ill., a corporation of Illinois.

Svenson's patent is on a method of effecting the resistance welding of workpieces and it includes mounting the workpieces to be welded upon a plurality of workpiece supports and applying welding potential to the workpieces. The workpieces are shifted relatively toward each other in a controlled pattern of movement including a rapid transverse approach and a reduced feed approach velocity followed by an increasing velocity acceleration relative to the feed approach velocity as the workpieces approach contacting juxtaposition. Thereafter the workpieces are impacted together with the welding potential applied thereto.

2,656,446—Electric Resistance Welding Tool—Adrien Albarrane, Paris, France.

This new tool relates to a portable welding tool including a handle, an electrode and an electrode-carrying member pivotally secured to the handle. A spring urges the electrode carrying member to an inoperative position with relation to the handle and two cooperating contact pieces are yielding carried by the electrode-carrying member and by the handle, respectively, and are adapted to engage one another as soon as the electrode-carrying member is urged into operative relationship with the handle.

2,656,447—Indicating Device for Seam Welding Apparatus—Frederic M. Darner, Shaker Heights, Ohio, and Walter S. Schaefer, East Gadsden, Ala., assignors to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

This patent relates to apparatus for welding a seam along a cleft in an article which is advanced in the direction of the cleft. The apparatus includes a supporting structure to engage the advancing article and a welding device positioned for adjustment relative to the supporting structure and the article crosswise of the cleft. Specialized indicating means are provided for indicating variations in the relative position of the cleft crosswise with relation to the supporting structure in order to aid in maintaining the weld means in desired relationship to the cleft.

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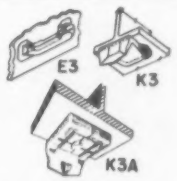

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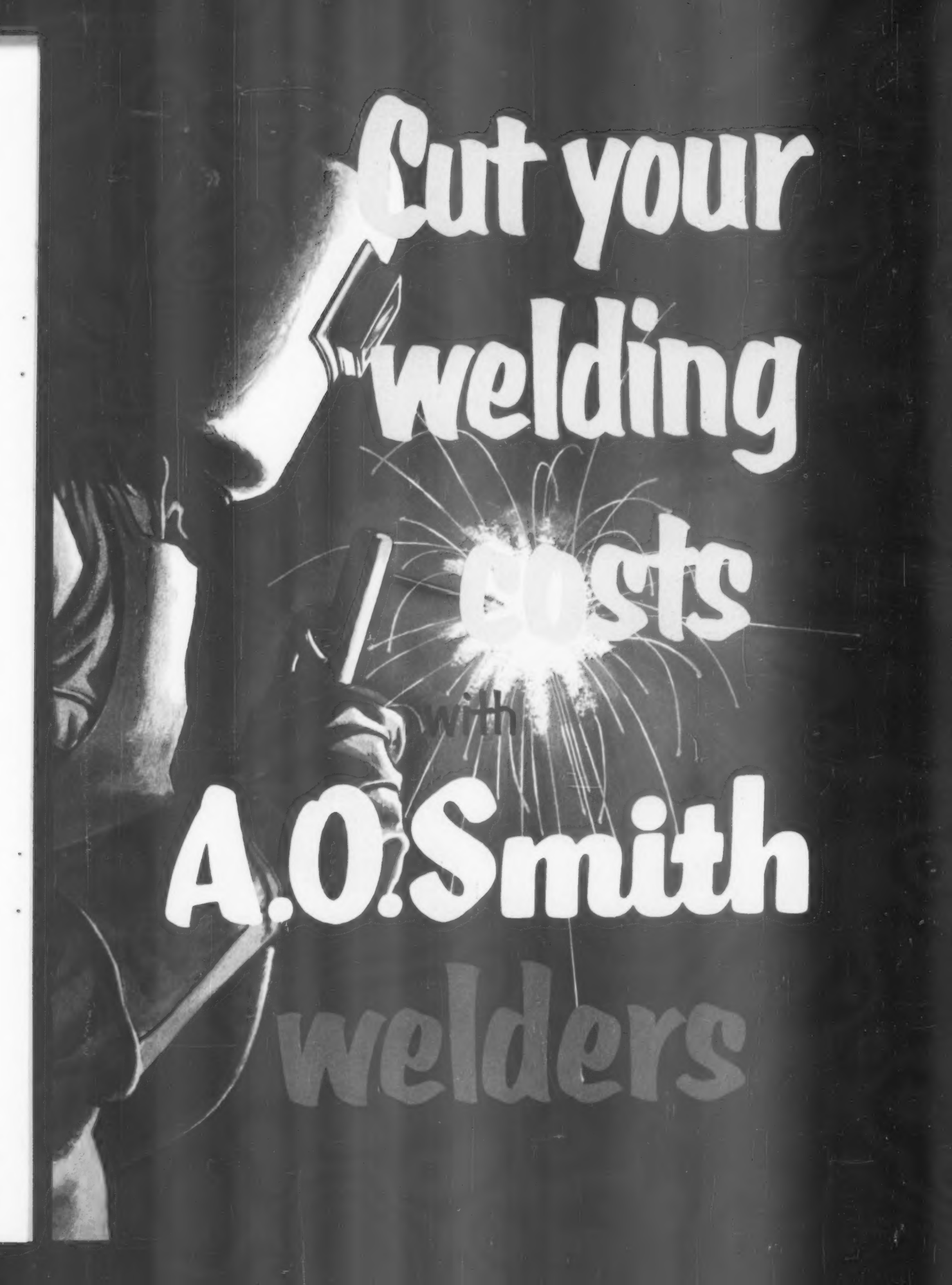
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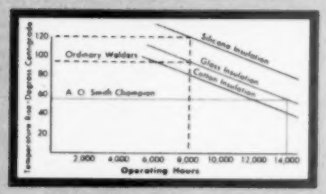

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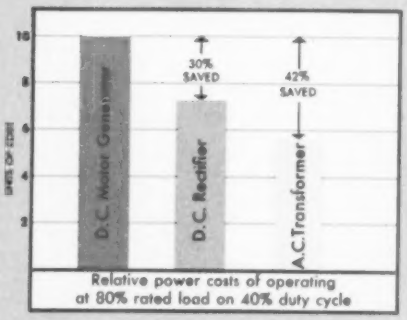

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Low Hydrogen	AWS Class	E6016	E6016	E7016	E8016	E9016	E9016	E10016	E12015	E12016
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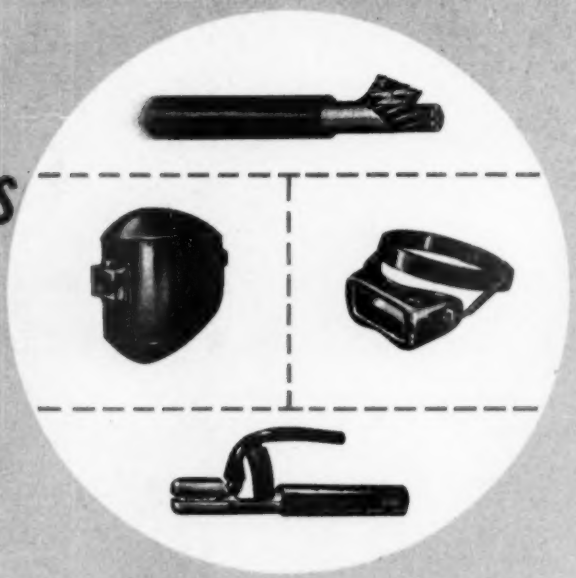

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Supplement to the Welding Journal, December 1953

Stabilizing Austenitic Chrome-Nickel Weld Metal Against Intergranular Corrosion

A 22% Cr–10% Ni electrode is proposed as a substitute for the usual columbium addition for protection against intergranular attack

by Hallock C. Campbell

Abstract

Suitable chromium and titanium additions to 18% Cr – 8% Ni weld metal will satisfactorily substitute for the usual columbium addition, for protection against intergranular attack. A 22% Cr – 10% Ni electrode is proposed for field testing.

The titanium was transferred across the arc by adding to the coating a titanium-aluminum alloy. In larger amounts this would impair the usability of the electrode, but by combining only small additions of titanium with varying percentages of ferrochromium, normal usability was achieved.

All-weld-metal specimens in the as-welded and in several heat-treatment states were subjected to accelerated corrosion tests in boiling 65% nitric acid, and in mixed nitric-hydrofluoric acids at 180° F. Vanadium was found unsatisfactory as a stabilizing element. Chromium proved more effective than titanium at the levels studied, which is attributed to the high silicon pickup accompanying the titanium additions. Corrosion resistance comparable to Type 347 and Type 308LC (extra low carbon) electrodes was obtained when the chromium level was about 22%.

Tensile strengths increased with alloy content whether as-welded or heat treated. All of the compositions exhibited good ductility under all conditions studied.

Hallock C. Campbell is the Associate Director of Research and Engineering, Arcos Corp., Philadelphia, Pa.

Presented at the AWS National Spring Meeting, Houston, Tex., June 16–19, 1953.

INTRODUCTION

INTERGRANULAR corrosion is the most serious attack which the stainless steels have to combat. Their resistance to the environments we customarily expose them to is generally quite adequate unless chromium depletion has occurred at the grain boundaries. Since precipitation of chromium carbide occurs throughout the 1000 to 1600° F temperature range, this attack may follow a welding operation, or heat treatment or service at temperatures around 1200° F.

The stabilization of parent metal and weld metal by columbium addition has been a fairly satisfactory solution to this problem. The addition of sufficient columbium to tie up the carbon in the steel gives practically complete freedom from intergranular corrosion. Except for cracking difficulties in heavy sections, the Type 347 columbium-bearing electrodes have been a sturdy and reliable member of the available welding compositions. The usability of these electrodes has been approximately the same as that of the unstabilized electrodes.

Then came the spectre of a columbium shortage. It was very real in 1951, and it may yet again arise to plague us. The substitution of ferro-tantalum-columbium proved to be satisfactory in most applications,[1] but in welding it did not prove economical because of the excessive losses which were experienced across the arc, resulting in no real conservation of columbium.

From the point of view of over-all economy for the country it was thus decided to continue the manufacture of columbium-bearing electrodes and to employ the tantalum-columbium alloy only in steel melting.

Titanium is an effective substitute for columbium in steel manufacture, and in some of the inert-gas-welding processes, as witness the many testimonials in *Metal Progress* in a survey of industry taken at the height of the columbium shortage.[2] While certain drawbacks are noted in the Type 321 steel (18–8 with titanium), it is still an adequately stabilized composition in most applications. Unfortunately Type 321 wire cannot easily be used as a welding electrode, because the titanium is almost entirely oxidized in the electric arc, resulting in an unstabilized weld deposit. The conventional electrode for welding Type 321 steel is thus the Type 347 electrode. But what is to be done if columbium is no longer available for electrodes?

It has been known for some time that titanium can be transferred across the arc when it is properly protected by a more active metal, such as aluminum.[3] Unfortunately, when sufficient quantities of titanium and aluminum are added to produce a Type 321 deposit, the usability of such electrodes is not good: the aluminum is preferentially oxidized in the arc, and the resulting alumina greatly changes the behavior of the slag. Poor visibility of the weld pool, a sluggish viscous slag and very difficult slag removal are the common defects.

The idea which sparked the investigations reported here was the possibility that one might secure adequate stabilization of 18–8 weld metal by a partial addition of titanium and a supplementary addition of some other stabilizing element. The possible alternates are the carbide-forming elements, particularly vanadium, chromium and zirconium, which are readily available as ferro-alloys in particle sizes suitable for electrode coating incorporation.

EXPERIMENTAL

Exploratory

The first consideration was the good usability of the electrode. The experiments were based on a lime-type coating. Satisfactory usability was earliest achieved with a coating containing a zirconium alloy (in addition to the allotted titanium-aluminum). However, relatively little zirconium was transferred across the arc, and the corrosion resistance of the deposit was poor. Several other elements were later tried, with similar success in regard to arc operation, but with dubious economic value because of high price, and with insufficient improvement in operation to merit further consideration.

Ferrovanadium was more promising. A series of coatings explored the effect on usability of several percentages of ferrovanadium and several levels of titanium-aluminum. A definite usability limit was met with the titanium-aluminum, but almost any amount of ferrovanadium could be used.

Good usability was also achieved with fairly large additions of ferro-chromium, both with and without vanadium and/or titanium additions.

The happiest choice of stabilizing elements thus would seem to depend largely on the relative corrosion resistance of these usable compositions. As a screening test an accelerated corrosion test in mixed nitric-hydrofluoric acids was used, applying it to all-weld-metal specimens in the annealed-plus-sensitized condition.

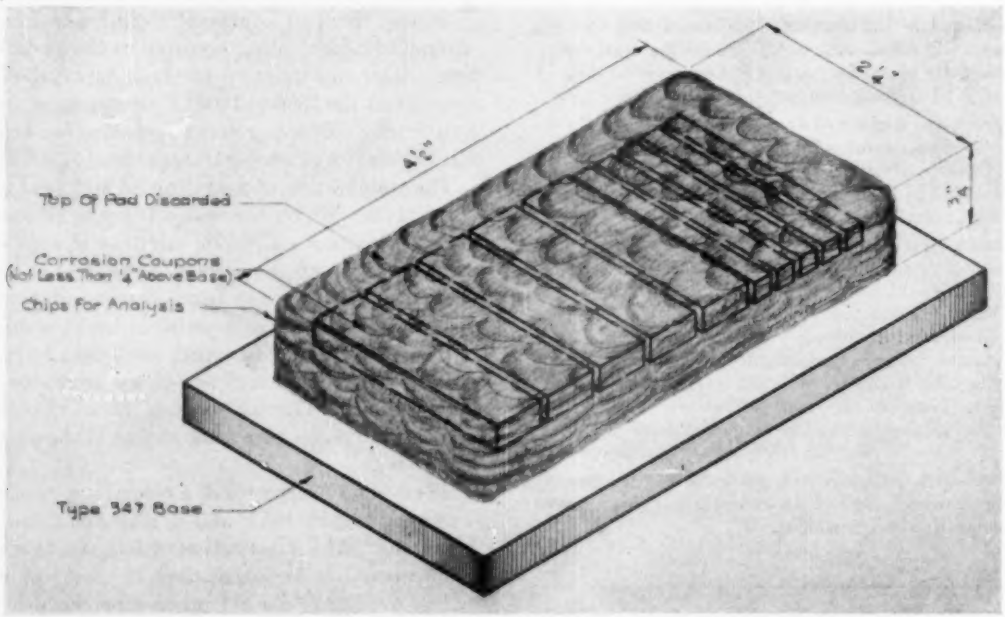


Fig. 1 Schematic drawing of weld pad for analysis and corrosion specimens
1/4- x 1/2- x 2-in. bars used for nitric acid test; 3/16- x 3/16- x 2-in. bars used for mixed acids test.

Table 1—Chemical Analysis Ranges

Series	Experiment Nos.	Carbon Avg	Carbon Range	Titanium* Avg	Titanium* Range
Cr	61, 62, 63	0.058	0.054–0.062	0.0	.....
Cr + Ti	64, 65, 66	0.061	0.058–0.066	0.10	0.08–0.12
Cr + C	71, 72, 73	0.068	0.065–0.070	0.0	.....
Cr + C + Ti	74, 75, 76	0.069	0.068–0.071	0.09	0.08–0.12
Cr + C + Ti	96	0.096	.....	0.08	.....

* Both silicon and manganese were significantly higher in the titanium-bearing welds than in the nontitanium welds. The average silicon levels were 0.30 in the 1, 2, 3 electrodes and 0.97 in the 4, 5, 6 series; the manganese values were 1.6 and 1.9, respectively.

This is a very severe test, and may have discouraged further study of otherwise promising compositions, but since adequately stabilized compositions were eventually discovered in this study, those electrodes which failed the mixed acids test were certainly of less value.

Vanadium, far from being beneficial, actually seemed to be harmful in this test. The weight loss, which indicates general as well as intergranular attack, and the visually observed intergranular attack on the specimens when double bent after exposure, both increased with increasing vanadium content. The best corrosion resistance was shown by the specimens containing only titanium as stabilizer, or chromium plus titanium.

Cr-Ti Electrodes

The investigation then narrowed down to a factorial study of chromium and titanium. Two levels of carbon, two levels of titanium and three levels of chromium were chosen, resulting in 12 compositions in all, all of which exhibited satisfactory usability. These electrodes were then tested in boiling 65% nitric acid, in mixed nitric-hydrofluoric acids at 180° F, and in all-weld-metal tension tests.

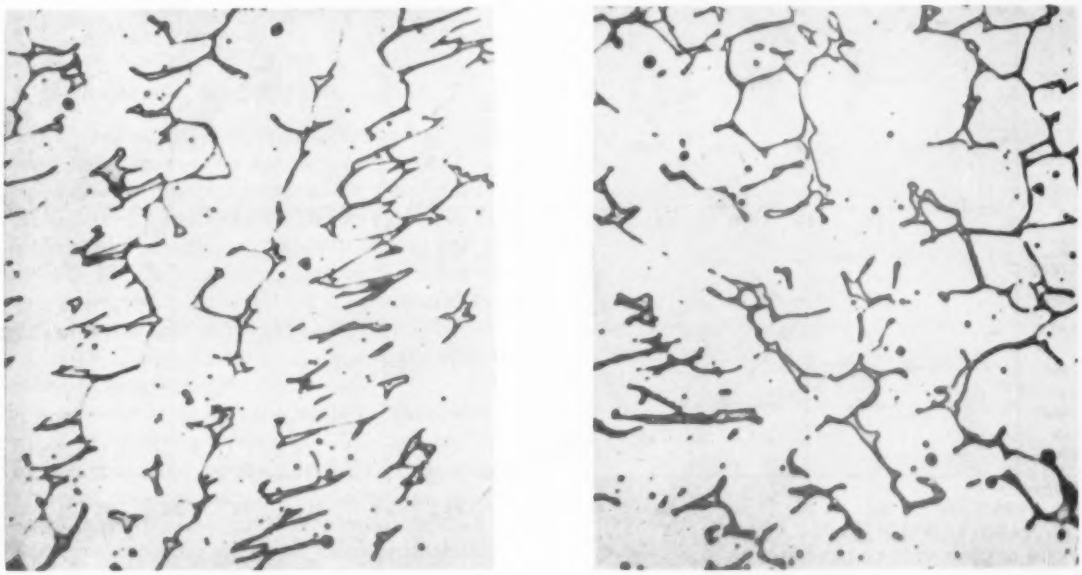
Samples for chemical analysis were obtained from the top layers of the corrosion pads as shown in Fig. 1.

The chemical analyses are given in full in the Appendix. The results are summarized more succinctly in Table 1. Thanks to the narrow spread of the analyses within each series, the general effects of the variation in chromium (plotted along the horizontal axis in each of the graphs), carbon and titanium may be observed directly from the graphs on which the experimental data are plotted.

Calculation of the ferrite-austenite balance using the Schaeffler diagram[4] gives ferrite percentages ranging from 5 to 15. These values were confirmed by etching the ends of the as-welded nitric acid bars. The agreement between calculated and observed ferrite contents is shown in Table 2. A factor of 3.5 was used in computing the chromium equivalent of the titanium. The

Table 2—Percent Ferrite

No.	61	62	63	64	65	66	71	72	73	74	75	76	96
Calcd.	5	7	10	7	10	12	5	8	10	8	12	15	15
Observed	5	9	10	4	13	14	3	5	9	9	14	14	7



Electrode 63 *Electrode 73*

Fig. 2 Typical Microstructure of 22Cr-10Ni Weld Metal in As-Welded Condition. At left, Electrode 63 (22Cr-11Ni-0.06C), about 10% ferrite. At right, Electrode 73 (22Cr-10Ni-0.07C) about 9% ferrite. Magnification 1000×; etched with Kallings reagents

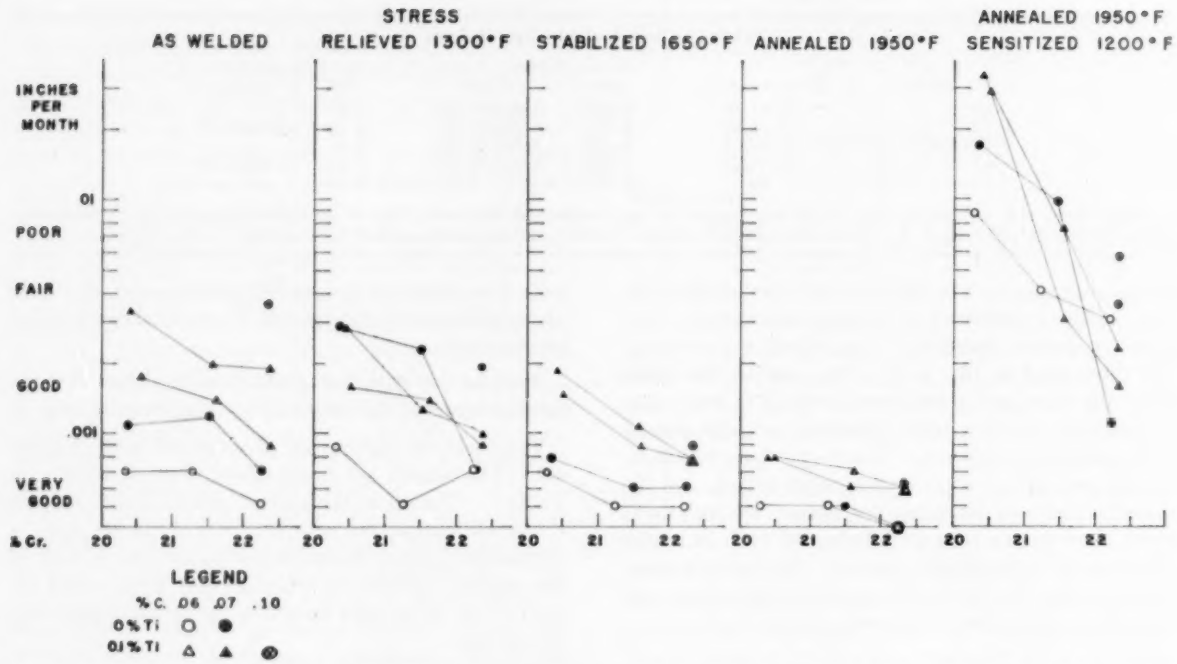


Fig. 3 Nitric acid corrosion rates: Penetration in inches per month computed from weight lost during five 48-hr periods in boiling 65% nitric acid; specimens given prior heat treatments as indicated

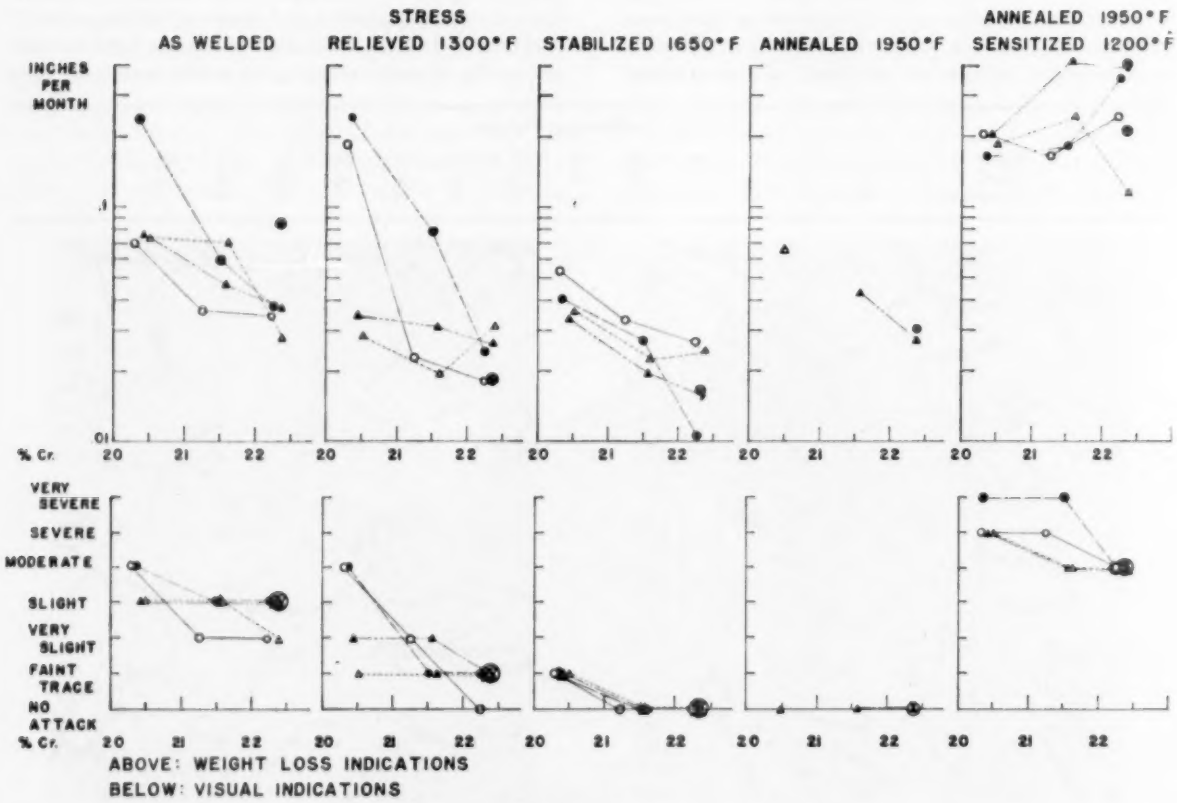


Fig. 4 Nitric-hydrofluoric acid corrosion test

Upper figures, inches per month penetration computed from weight lost during four 1-hr periods at 180° F in mixture of 10% nitric acid and 3% hydrofluoric acid; lower figures, visual estimate of degree of intergranular penetration based on surface appearance of corrosion bars after being bent double at end of test.
Very slight = attack difficult to see with naked eye. Faint trace = attack visible only with aid of binocular microscope.

appearance of typical weld deposits of the 63 and 73 electrodes (22% Cr – 10% Ni) is shown in Fig. 2.

Boiling Nitric Acid Corrosion Tests

The corrosion specimens were rough machined, then heat treated in a laboratory muffle furnace, finally finished machined. The specimens were suspended in the acid in individual flasks, each specimen resting in a glass cradle (ASTM Procedure A262–52T).

The customary heat treatments were studied: *as-welded*, to examine the possibility of eliminating all heat treatments; *stress relieved* (1300° F for 2 hr), a possible treatment for heavy weldments or those which cannot be given a stabilizing treatment; *stabilized* (1650° F for 2 hr), as required for some pressure vessels; *annealed* (1950° F for $^1/_2$ hr and water quench), to serve as a control point and to indicate the optimum condition; and *annealed plus sensitized* (1950° F for $^1/_2$ hr, water quench, plus 1200° F for 1 hr), to reveal the worst corrosion attack which may be experienced in service.

The results of the nitric acid test are summarized in Fig. 3.

As might be expected, chromium has a remarkable influence in the nitric acid test in all heat-treatment conditions, especially after the annealed-plus-sensitizing treatment. The one-point difference in carbon exhibited by the two core wires in this study is more evident in the as-welded and stress-relieved conditions than after the higher postwelding heat treatments. The titanium addition invariably shows a higher nitric acid corrosion rate than the corresponding nontitanium composition, probably because of the higher silicon content which accompanied the titanium additions. Silicon is known to have an adverse effect on the results of this test.

Nitric-Hydrofluoric Acid Corrosion Tests

The 10% nitric – 3% hydrofluoric "mixed acids" accelerated corrosion test was conducted on $^3/_{16}$- x $^3/_{16}$- x 2-in. specimens. After completing four 1-hr periods at 180° F and computing the weight loss corrosion rate, the specimens were clamped in a vise at one end and bent double by hammer blows against the other end. The degree of intergranular attack was evaluated from the surface appearance of the specimens.

The results of exposing the weld metal to this severely corrosive test are pictured in Fig. 4.

The specimens show only moderate or slight attack, or none at all, with the exception of the sensitized bars. The highest chromium specimens exhibit only moderate intergranular attack, even in the sensitized state.

The effect of the one-point difference in carbon level is shown by comparing the open points with the solid points. The adverse effect of this difference of carbon is relatively slight.

The titanium influence appears to be negligible except for the stress-relieved low-chromium specimens. However, in this test as in the nitric acid test, silicon may have an adverse effect, thus counteracting the beneficial effects of the titanium.

In general the nitric-hydrofluoric acid test, which is so severe in its attack that its "acceleration" gives results in hours instead of days, seems insensitive to the slight difference in carbon level and the balancing effect of the titanium and silicon of these experiments. Nonetheless, the effect of chromium is unmistakable, and the tests are considered valuable as confirmation of the evidence brought out by the nitric acid test.

The degree of success which has been attained in the search for a columbium-free weld composition may be observed in Fig. 5. In this chart the data for the chromium-reinforced 63 and 73 electrodes have been averaged and plotted against standard electrode data. The bars representing Types 347, 308 and 308LC are taken from a previously published study conducted under similar conditions.[1]

This chart clearly demonstrates that the "chromium-stabilized" weld metal is certainly equivalent to, if not better than, the columbium-stabilized Type 347 weld metal in all conditions except the most severe annealed-plus-sensitized state.

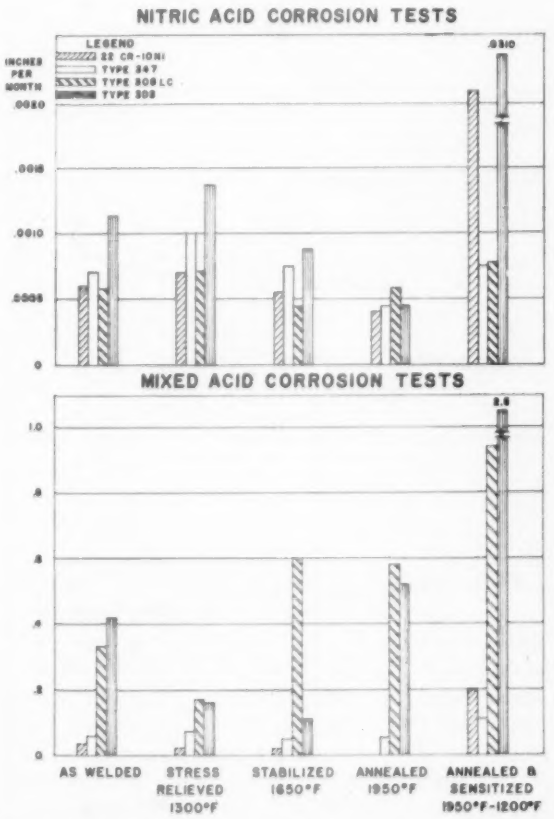


Fig. 5 Comparison of corrosion test results for stabilized and unstabilized weld metal. Data for 22% Cr – 10% Ni electrode taken from Figs. 3 and 4; data for Type 347, Type 308LC, and Type 308 taken from the literature[1]

Tensile Properties

In these compositions one would not expect to find abnormal strength or ductility, or any lack of soundness, in any of the weld deposits, but it still seemed advisable to prepare standard tensile bars to verify this expectation. The highest chromium content might, for example, become embrittled in some of the heat-treated states. The high silicon accompanying the titanium addition might lead to weld cracking or fissuring. The combination of high carbon and high chromium might lead to rather low ductility, just because of the very high strength it might give.

The electrodes were deposited in vee-groove butt welds in $^3/_4$-in. mild steel plate with doubly clad or buttered edges, otherwise following the standard AWS-ASTM procedure for stainless steel electrodes (A298–48T). The results are shown in Fig. 6.

The specimens were all sound. This was encouraging confirmation of the theoretical expectation. The ductility was high. Even at 90,000 psi tensile strength the elongations were over 36% in 2 in.

The tension data for the chromium-only electrodes (63 and 73) show that these compositions are normal in their behavior. The room temperature strength is above that of a standard 308 electrode and of course above the specified minimum for Type 308 in the AWS-ASTM specification A298–48T. The ductility is also good. The elongation (over 38% in 2 in. in each of the tests run) is far above the minimum specified for Type 347 electrodes (30%) and even above the highest elongation required of any electrodes in that specification (35%, for Types 308 and 309).

The effect of carbon in this study was that which would be expected: an increase in strength and a slight decrease in ductility.

The effect of titanium was favorable on several counts. The increase in strength at each chromium level was pronounced, averaging 7000 psi in yield value and 6000 psi in ultimate strength. The corresponding decrease in elongation was slight, the elongation averaging only 1% less for the titanium-bearing welds than for the nontitanium welds. Surprisingly enough, the

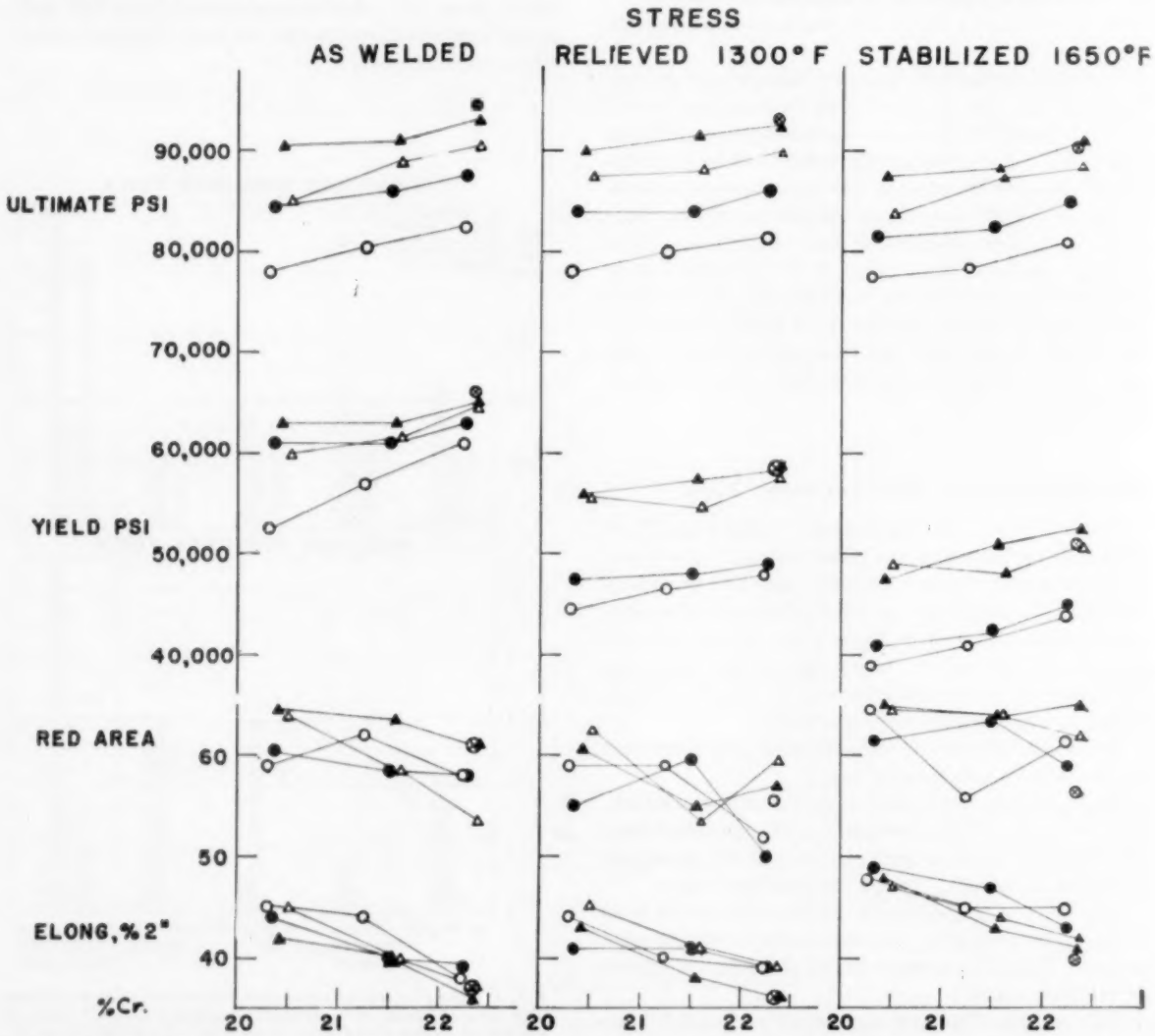


Fig. 6 All-weld-metal tension tests: 0.505-in. diam bars tested at room temperature after heat treatments shown

reduction in area values actually improved with the titanium addition, the titanium welds averaging 2% higher in reduction than their counterparts. If the corrosion rates had not been so unpromising, the Cr+Ti compositions would indeed have merited further consideration.

CONCLUSIONS

A 22% Cr – 10% Ni electrode composition is proposed as a substitute for the Type 347 electrode for applications requiring resistance to intergranular corrosion. The screening tests reported here show low corrosion rates for this composition both in the as-deposited condition and also after the four conventional heat treatments, including sensitization at 1200° F for 1 hr. The room temperature tension properties are superior to the highest requirements of the AWS-ASTM electrode specifications.

The columbium shortage has encouraged the use of Type 321 steel for many of the corrosion applications in which Type 347 was formerly used. The 22% Cr – 10% Ni electrode would be a logical choice for welding this steel, as it would give corrosion service equal to or better than that of a Type 347 electrode, and at the same time would permit further conservation of columbium. When the nature of the service requires the use of a columbium-stabilized steel, however, there would be less inclination to recommend a substitute for the standard Type 347 electrode.

This study has been concerned principally with corrosion properties. Although heat treatments of the types normally employed in fabrication were investigated, it is not possible to draw any conclusions from them as to the suitability of the electrode for service involving strength at high temperatures. Nevertheless, in many high-temperature applications, especially those involving surface oxidation or scaling, it is not unreasonable to expect that this noncolumbium electrode might outperform Type 347.

ACKNOWLEDGMENT

Many thinks are due R. David Thomas, Jr., for assistance and encouragement in this project from the original planning to the final reporting. Also gratefully acknowledged is the collaboration of the many colleagues who were involved in the work.

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3. Thomas, R. D., Jr., and Comstock, G. F., U. S. Patent 2,464,836 (Mar. 22, 1949).
4. Schaeffler, A. L., *Metal Progr.*, **56**, No. 5, 680-B (November 1949).

Chemical Analysis of Electrode Deposits

No.	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*Ti*	*N*	*Observed ferrite, %*
61	0.054	1.60	0.32	0.012	0.007	20.29	10.85	Trace	0.123	5
62	0.058	1.55	0.32	0.008	0.004	21.23	10.72	None	0.076	9
63	0.062	1.60	0.32	0.013	0.009	22.22	10.75	None	0.068	10
64	0.058	1.94	1.04	0.011	0.008	20.50	11.14	0.12	0.062	4
65	0.066	1.96	1.00	0.010	0.009	21.60	11.14	0.10	0.067	13
66	0.059	1.84	0.96	0.015	0.008	22.37	10.78	0.08	0.074	14
71	0.065	1.60	0.26	0.012	0.011	20.34	10.25	Trace	0.114	3
72	0.070	1.57	0.29	0.010	0.011	21.50	10.07	None	0.108	5
73	0.068	1.65	0.28	0.008	0.010	22.16	9.96	Trace	0.114	9
74	0.068	2.02	1.02	0.007	0.011	20.41	10.26	0.12	0.079	9
75	0.068	1.94	0.95	0.008	0.023	21.56	9.95	0.08	0.091	14
76	0.071	1.86	0.92	0.009	0.024	22.36	9.74	0.08	0.091	14
96	0.096	1.86	0.91	0.011	0.023	22.34	9.49	0.08	0.098	7

Discussion by Allan J. Rosenberg

I am very appreciative of the opportunity that has been extended to me to comment on this fine paper. The problem with which it is concerned, the possible shortage of columbium for metal-arc welding electrodes, was a very real one to the General Electric Co. a few years ago, and it is one which may again present itself at any time. The titanium-stabilized Type 321 had already been successfully substituted for 347 sheet metal parts throughout most of our operation, but the question of a suitable substitute-stabilized electrode for welding these steels was a major concern.

Anticipating that the day of columbium-stabilized electrodes might end, the possibility of employing other commercially available austenitic electrode materials was thoroughly investigated. Included in this group were a Type 347 electrode as a standard, and Types 308, 308 with extra-low carbon and Type 316. Of particular interest was the weld-joint properties in Type 321 base material. Tensile properties at room and elevated temperatures as well as stress rupture data were therefore compiled. In every case the joint

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mechanical properties were comparable and thus strength was no problem.

Samples were then sensitized at 1200° F for 2 hr and subjected to a standard 72hr Strauss test in boiling copper sulphate-sulfuric acid solution. Intergranular attack in the Type 347 welded joint after this was only spotting, to a depth of 0.002 to 0.003 in. The Type 316, which has molybdenum added to impart passivity and which also forms moly carbides, suffered approximately the same attack; so did the Type 308 with extra-low carbon. It was only the unstabilized Type 308 electrode which suffered general weld-bead corrosion and complete intergranular attack through the heat-affected zone. Now some definite data were available on which to base a substitution for Type 347 should that become necessary. Unfortunately the 308 extra-low-carbon electrode which appeared so promising was even more difficult to obtain than the 347 one, so that our choice for a 347 substitute today would be the Type 316 material.

Dr. Campbell's approach to this corrosion problem is a logical and refreshing one and is a definite advancement in the art of electrode manufacture. I should, however, like to pose three questions concerning this new composition. First, does Dr. Campbell feel that the 22-chrome, 10-nickel electrode will offer an advantage over the already existing Type 316 or over other compositions involving molybdenum? Second,will the additional chromium in the electrode tend to increase the possibility of sigma phase, a condition which can exist even with the 347 electrode? And finally, since the 22-chrome, 10-nickel electrode performs poorly in the nitric acid test after the severe conditions of annealing and sensitizing, should it not be used with caution where such conditions could conceivably exist, such as, in normal production where parts might be welded, annealed, have additional welding performed, be stress relieved, etc.?

There should be no question that the new electrode will perform completely satisfactorily in many applications. As Dr. Campbell has intimated, field testing must be carefully evaluated.

Author's Reply

I greatly appreciate the comments by Mr. Rosenberg and by the others who took part in the oral discussion.

The 22/10 electrode should certainly prove better than Type 316 in corrosion resistance to nitric acid and to solutions which behave similarly in the nitric acid test. However, as was pointed out in the Discussion, Mr. Rosenberg is not proposing that Type 316 be used for nitric acid service, or that a 22/10 electrode be used in the sulfates and sulfites which the molybdenum-bearing steels resist so well. When it comes to aircraft applications we admittedly have no direct information and must wait for field tests.

The 22/10 composition should not be more susceptible to sigma formation than Type 347. The absence of columbium is an advantage, as this element does seem to hasten the formation of sigma.

I am indebted to Mr. Rosenberg for pointing out ways in which the annealed-and-sensitized condition may occasionally be met in practice. His word of caution is well taken.

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Low-Temperature Bend Test Properties of Bead-on-Plate Welds

Low-temperature bend test properties of bead-on-plate welds of low-hydrogen and cellulosic type electrode with and without preheating and postheating

by L. A. Harris, R. B. Matthiesen and N. M. Newmark

Summary

Studies are reported on the low-temperature bend test properties of notched E6010 and E6016 bead-on-plate welds subjected to various treatments. The beads were deposited on steels which were selected to correspond to ASTM designations A7, A285C and A242. The effects of low-temperature cooling rate embrittlement were investigated by testing welds which were water quenched after welding. In addition, the effects of preheating and of postheating were studied. Separate series of specimens were tested with the direction of the applied stress either parallel to or transverse to the direction of welding. The base of the notch was located so that the properties of the specimens could be investigated at the center of the weld metal, near the fusion line, or in the heat-affected zone. In order to compare the bend properties of the specimens notched to different depths, the results are interpreted in terms of the proportion of the maximum deflection of corresponding plain plate specimens. An investigation of the effects of the weld reinforcement on the bend properties and of the method of interpretation of the weld-bead bend test is contained in the Appendix.

INTRODUCTION

STUDIES have shown that the use of the low-hydrogen electrodes may solve some of the problems encountered in the welding of the more difficult to weld steels. Cracking in the heat-affected zone is frequently eliminated and a sounder, more ductile weld produced. For the structural steels the effects of high hydrogen contents are associated principally with cracking in the weld metal. Several investigators[1–4] have noted microcracks in weld metal having high hydrogen contents and subjected to rapid low-temperature cooling rates. In an extensive investigation of the bend properties of bead-on-plate welds, Flanigan and Kaufman[3] have reported on the occurrence of microcracks in E6010 weld beads on an ASTM A285C steel quenched shortly after welding. They found that the microcracks were concentrated at about the mid-depth of the weld metal and were oriented in a direction prependicular to the direction of welding. The reduced ductility of the E6010 water-quenched bend specimens notched in the weld metal was generally associated with microcracking under conditions of rapid low-temperature cooling rates.

In the present investigation, the weld-bead bend test has been employed to compare the properties of the bead-on-plate welds produced by the high-hydrogen E6010 and the low-hydrogen E6016 electrodes. The main portion of the program included a study of the effects of the low-temperature cooling rate, of preheating and of postheating for welds on steels corresponding to ASTM designation A7, A242 and A285C. The effects of these conditions were investigated at three regions of the weld cross section (in the weld metal, near the fusion line and in the heat-affected zone) with the bending stress applied either parallel to or perpendicular to the direction of welding.

The Appendix contains a study of the effect of the geometry of the weld reinforcement, which projects above the surface of the plate, on the bend test properties of bead-on-plate welds and a study of the method of interpretation of the weld-bead bend test.

PREPARATION AND EXAMINATION OF BEND SPECIMENS

Descriptions of Steels

Steels were selected to conform to ASTM designations A7, A242 and A285C (firebox quality), which correspond to Steels B, D and E, respectively, in this report. As indicated in Table 1, Plates 5 and 6 of Steel B do not meet the requirements of ASTM designation A7 for tensile strength or yield point. Plate 4 of Steel B and Steels E and D meet their respective requirements for physical properties and chemical analysis.

Weld Metal Properties

The results of chemical analyses and tensile tests of

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Presented at the AWS National Fall Meeting, Cleveland, Ohio, Oct. 21, 1953.

Table 1A—Chemical Analysis of Plate Materials

Steel	Chemical composition, % C	Mn	P	S	Si	Cu	Ni	Cr
B, 3/4 in., A7	0.23	0.48	0.014	0.032	0.03	...	...	...
B, 1 in., A7	0.28	0.51	0.018	0.041	0.03	...	...	...
D, 3/4 in., A242	0.16	0.58	0.108	0.034	0.45	0.34	0.28	1.00
E, 3/4 in., A285C	0.21	0.55	0.012	0.035	0.02	...	...	...

Table 1B—Physical Properties of Plate Materials

Steel	Yield point, psi	Maximum strength, psi	Elongation in 8 in., %
B*, Plates 5, 6, 3/4 in., A7	32,100	57,400	32
B,† Plate 4, 3/4 in., A7	35,000	61,100	30
B,‡ Plate 1, 1 in., A7	39,000	68,900	30
D, Plate 2, 3/4 in., A242	51,000	78,100	27
E, Plates 2, 1, 3/4 in., A285C	35,300	60,600	31

* Used for weld-bead series.
† Used for machined-weld series.
‡ Used for simulated-bead series.

all-weld-metal specimens prepared in accordance with ASTM designation A233–48T are presented in Table 2. These results show that the E6016 electrode deposited weld metal having a tensile strength and an upper yield point about 10,000 psi greater than that deposited by the E6010 electrode.

The E6016 weld metal has the same carbon content as the E6010 weld metal, but the manganese and silicon contents are higher. This is probably one of the factors contributing to the higher strength of the weld metal deposited by the low-hydrogen electrode; another factor might be the numerous gas pockets present in the E6010 weld metal. The low-hydrogen weld metal appeared to be free from visible defects.

Table 3—Welding Variables

Electrode	Voltage, v	Current amp	Rate of travel, ipm	Energy input, joules per in.
E6010	25	170	8	31,900
E6016	21	200	8	31,500

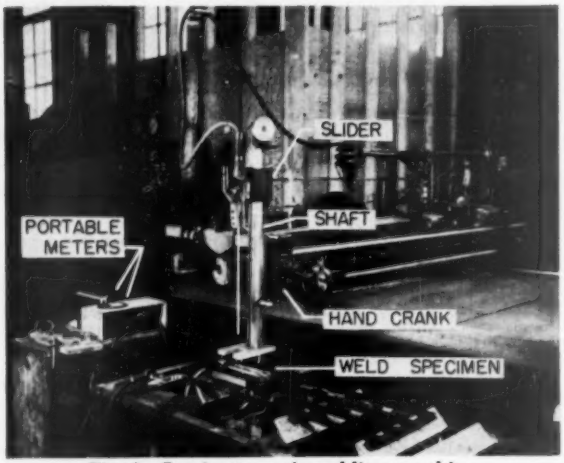

Fig. 2 Semiautomatic welding machine

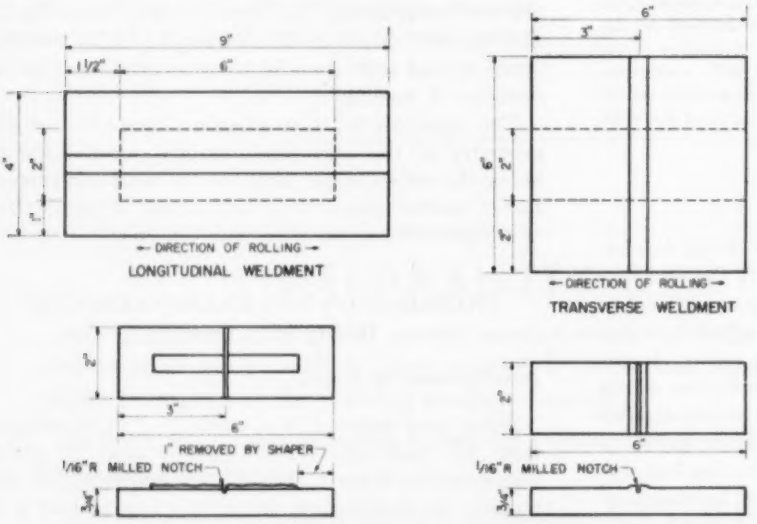

Fig. 1 Longitudinal and transverse weld-bead specimens

Welding Procedure

Two types of weld specimens (see Fig. 1) were employed in the preparation of the bend specimens: (1) the 4- by 9-in. longitudinal weldment and (2) the 6- by 6-in. transverse weldment.

The direct current for welding was supplied by a 400-amp capacity generator of standard manufacture, which was set to the values indicated in Table 3. A semiautomatic welding machine was adapted from an oxyacetylene flame-cutting machine. As shown

Table 2—Chemical Analysis and Physical Properties of All-Weld-Metal Samples

Electrode	Yield point, psi	Maximum strength, psi	Elongation in 2 in., %	Chemical composition, % C	Mn	P	S	Si
E6010	55,900	65,600	23	0.11	0.63	0.012	0.030	0.27
E6016	65,400	75,600	31	0.11	0.96	0.014	0.022	0.36

in Fig. 2, the electrode feed was controlled by a hand crank, which moved a slider on which a standard electrode holder was mounted. The slider travels on an adjustable shaft which controls the angle of inclination of the electrode. This welding machine made possible the automatic regulation of the direction of the rate of travel of welding; hence, the operator had to control only the feed of the electrode.

All of the electrodes were dried at a temperature of about 220° F for at least one week prior to use. Preliminary tests had indicated that there was no difference in the test results of specimens produced from dried and from undried electrodes; however, drying was continued to limit the hydrogen present in the arc atmosphere to that produced by the decomposition of the electrode coating.

The welds were either air-cooled or water-quenched after welding to establish the extent of "hydrogen embrittlement" under conditions of rapid low-temperature cooling rates. These conditions of cooling are referred to as AC (air-cooled) or Q-*X* (water quenched *X* minutes after welding). The cooling curves for the two specimen types, shown in Fig. 3, indicate that only the low-temperature (below about 375° F) cooling rate was affected by the quenches employed in these tests.

In order to study the effect of heat treatments, the welds were prepared either without heat treatment, were preheated to 450° F for 1 hr, or were postheated to 1150° F for 1 hr.

Cooling Rate of Weld Specimens

To determine the cooling rate, chromel-alumel thermocouples, prepared from 28-gage wire, were coated with a commercial ceramic and inserted in 0.081-in. diam holes (filled with the liquid ceramic material) which were drilled to within 0.15 in. of the surface of the plate directly under the path of the weld bead. The output of the thermocouples was recorded automatically with a Heiland magnetic oscillograph (Type SE-303R-12) with the paper drive, the galvanometer wiring and the lamp controls modified for this application.

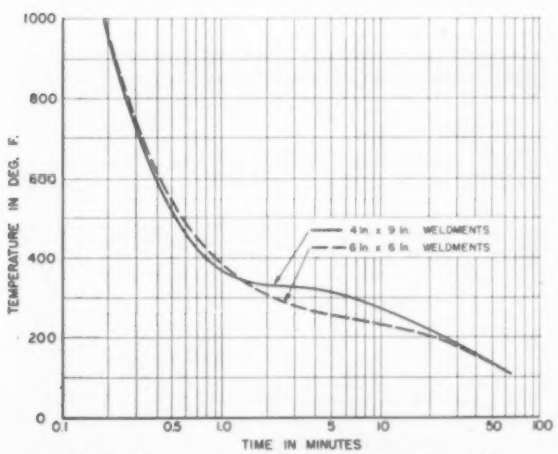

Fig. 3 Cooling curves for bead-on-plate welds

The cooling curves for the two types of specimen, shown in Fig. 3, are indicated as an average of all tests of similar specimens and compare favorably with the curves obtained by Flanigan, Bocarsky and McGuire[5] with thermocouples imbedded in the weld metal. There was no discernible difference between the cooling curves for the E6016 and the E6010 weld beads. The cooling rates at the temperatures above about 400° F are virtually the same for the two specimens types, whereas below 400° F, the 6-in. by 6-in. transverse specimen cooled more rapidly than the 4-in. by 9-in. longitudinal weld specimen. At temperatures below 400° F the mass of the specimen beyond 2 in. from the weld apparently influences the cooling rate.

Hardness Surveys

Vickers hardness surveys were made on cross sections cut transversely to the direction of welding. The specimens were given a metallographic polish, etched with 5% Nital, and indented with a Vickers, square base diamond pyramid in a Tukon Machine using a load of 1 kg. The surveys were made along the lines shown at the top of Table 4. The indents were spaced 1.5 mm in the weld metal, 0.5 mm in the heat-affected zone (starting 0.25 mm from the fusion line) and 1.5 mm vertically or 0.5 mm horizontally in the base metal.

Table 4—Results of Vickers Hardness Surveys

		Vickers Hardness Values		
Hardness series	*Specimen**	*Weld metal*	*Heat-affected zone*	*Base metal*
1	E6010 AC	202–219	184–222	123–163
1	E6010 Q-1	187–231	180–236	125–157
1	E6016 AC	213–231	171–212	126–158
1	E6016 Q-1	212–227	177–224	120–156
2, 3	E6010 AC	...	183–245	137–169
2, 3	E6010 Q-1	...	182–245	134–163
2, 3	E6016 AC	...	189–252	138–179
2, 3	E6016 Q-1	...	171–253	140–166

* AC = Air cooled after welding. Q-1 = water quenched 1 min after welding.

In Table 4, the tabulated data for the four specimens show no trend or any characteristic difference in hardness. As a general statement, it will be noted that the weld metal hardness is always greater than that of the base metal, but is less than the maximum hardness of the heat-affected zone in lines 2 and 3.

Hydrogen Analyses

Analyses were made for the hydrogen present after room storage for one day. Some specimens were stored at 150° F for 24 hr, but no difference in hydrogen content could be established. The samples, which weighed from $1^1/_2$ to 5 g, were cut to size with a saw and a metallurgical cut-off wheel. After cutting, the samples

Table 5—Summary of Results of Hydrogen Analyses (Hydrogen Concentration in Parts per Million)

Base-plate specimens			Core wire	
Steel B	*Steel D*	*Steel E*	*E6010*	*E6016*
1.3	0.0	0.1	0.8	0.0
0.6	0.0	0.0	0.3	0.0
0.1	...	...	0.0	...
0.0	...	...	0.5	...
			0.0	
			2.2	...

Specimen of entire weld cross section

Steel B		Steel D		Steel E	
E6010	*E6016*	*E6010*	*E6016*	*E6010*	*E6016*
1.5	0.0	3.9	0.5	3.8	0.2
1.6	0.0	3.1	0.2	2.3	0.2
1.1	0.0	...	...	2.4	0.1
3.0	0.0	...	...	2.8	0.4
1.5	0.0	...	...	1.6	0.5
1.2	0.0	...	...	0.7	...
1.2	...	...	...	...	...

Concentration through weld cross section (on Steel E)

Weld metal			Heat-affected	Base
Top	*Middle*	*Bottom*	*zone*	*plate*
0.0	1.2	0.2*	0.0	0.1
0.7	1.7	0.6*	0.1	0.0
0.9	1.3	3.7	0.3	0.7
...	3.2	...	0.4	0.3
...	1.7	...	...	...

* Poor fusion in analysis—probably low.

were filed smooth, cleaned in CP acetone and benzene, and dried in a stream of dry nitrogen. The analyses were performed at the Anderson Physical Laboratory, Champaign, Ill., using an analysis train similar to that reported by Carney, Chipman and Grant,[6] modified to analyze for hydrogen by a calibrated thermal conductivity cell.

The results of the hydrogen analyses are presented in Table 5. On the basis of the generally low hydrogen contents of the core wire and the base plate specimens, it is apparent that most of the hydrogen present in the welds must have been derived from the electrode coating. An examination of the results of the analyses of the weld specimens shows that the low-hydrogen welds contained little, if any, hydrogen. The hydrogen contents of the high-hydrogen welds on Steels E and B appear to be approximately the same, whereas Steel D possibly contains more, although no definite conclusion can be based on the small number of tests.

A limited investigation of the hydrogen concentration through the weld cross section indicated that there was only a very small amount of hydrogen in the heat-affected zone or in the base plate. In the weld metal, three portions of the cross section were examined: the top, the middle and the bottom. The hydrogen concentration might be somewhat lower in the top of the weld than at the middle. The analyses of the material at the bottom of the weld were too inconsistent to formulate any conclusions other than that hydrogen was present.

Microcrack Investigation

Table 6 describes the specimens which were examined for the presence of microcracks. The specimens, cut as small as $1^1/_4$ in. long, were prepared from longitudinal weld specimens.

The Series 1 and 2 specimens were cut from bead-on-plate welds surface-ground to remove the weld reinforcement and the original plate surface to a depth of 0.020 in. and then polished through the stages No. 3, 1, 1/2, 0 and 2/0, and wet grinding with No. 600 alundum and No. $303^1/_2$ emery on lead laps. These specimens were subjected to a magnaflux examination, using the fine standard red-colored magnaflux particles left suspended in kerosene after the coarse particles has been settled out.

At all stages of polishing (including surface grinding), all of the specimens showed indications of magnetic particle accumulations which had the appearance of microcracks. However, only the indications in Specimen B21B (E6010 quenched 1 min after welding) were sharp and could be repeated in the same regions by wiping off and remagnafluxing, establishing the existence of microcracks in this specimen. The magnaflux

Table 6—Specimens Examined for Microcracks

Specimen	*Electrode*	*Quench**	*Microcracks*
		Series 1	
B21A	E6010	AC	None (electropolish)
B21B	E6010	Q-1	Many (magnaflux and macro-etch)
		Series 2	
B38E	E6016	AC	None (mechanical polish)
B38F	E6016	Q-1	None (mechanical polish)
		Series 3	
B56A	E6010	AC	None (electropolish)
B56B	E6010	Q-2	Many (magnaflux and macro-etch)
		Series 4	
B71A	E6010	AC	None (electropolish)
B71B	E6010	Q-2	Few (magnaflux and electropolish)
B71C	E6016	AC	None
B71E	E6016	Q-2	None

* AC = Air cooled after welding. Q-1 = Water quenched 1 min after welding. Q-2 = Water quenched 2 min after welding.

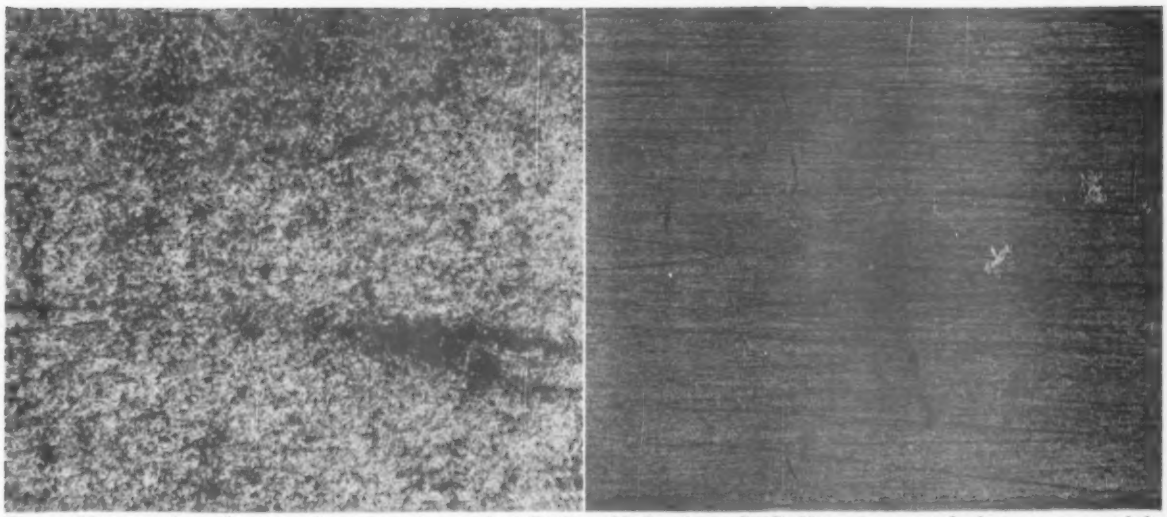

Fig. 4 Microcracks in horizontal section of quenched E6010 weld, Specimen B21B, 20 ×, macro-etched appearance at left, magnaflux indications at right

indications of microcracks became progressively sharper as the specimens were polished.

The specimens were then macroetched by immersion for 6 min in a solution of 500 cc of concentrated HCl, 70 cc of concentrated H_2SO_4 and 180 cc of H_2O at a temperature of 160° F. Examination of this surface at 20 × showed the presence of microcracks in Specimen B21B where the magnaflux had previously indicated them, but no trace of microcracks were revealed in the other specimens.

The series 2 specimens and Specimen B21A were further processed by mechanical metallographic polishing and examined for microcracks, but none were found. Specimen B21A was electrolytically polished in a chrom-acetic bath, but no cracks were found.

The appearance of the magnafluxed surface of Specimen B21B is shown in Fig. 4*A* and of the macroetched surface in Fig. 4*B*. The indication of microcracks by the macroetch is quite sharp when the specimen is initially taken from the bath, but the surface becomes stained by exposure to air.

On conclusion of the magnaflux tests, the Series 1 specimens were metallurgically polished along a longitudinal plane normal to the plate surface through and parallel to the weld bead. Microexamination of the as-polished surface showed the microcracks in Specimens B21B, as shown in Fig. 5.

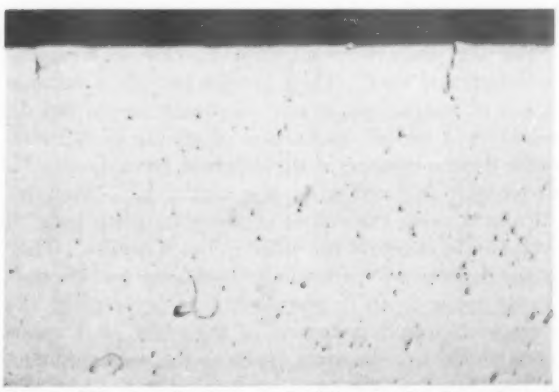

Fig. 5 Microcracks in unetched longitudinal section of quenched E6010 weld. Specimen B21B, 100 ×

The magnaflux indications on the horizontal surface were counted in nine fields at 20× and gave an average frequency of 57 microcracks per inch, although the density of cracks varied greatly in the different fields. The microcracks in the horizontal and vertical surfaces of specimen B21B were practically normal to the plate surface; thus, the microcracks represent planes of failure almost exactly normal to the direction of welding. It should be noted that these microcracks are similar to those reported by Flanigan and Kaufman.[3]

Further examination was made by the following procedures. For Series 3, the as-deposited weld specimens were stressed to their yield point in bending on a $4^1/_2$-in. span at −90° F, with the weld bead in tension, and then surface ground to a depth of 0.020 in. For Series 4, the specimens were surface ground to a depth of 0.020 in. before bending to their yield point. The quenched E6010 welds of Series 3 and 4 both gave evidence of microcracks, but the indications were more easily found in the specimens strained before removing the bead. No microcracks were found in the other specimens.

Preparation of Weld-Bead Bend Specimens

For the 4- by 9-in. longitudinal weldment, a 9-in. weld bead was deposited along the major axis of the specimen, and a 2- by 6-in. longitudinal bend specimen was subsequently prepared from the weldment so that the direction of the applied bending stress would be longitudinal, parallel to the direction of welding.

The 6- by 6-in. transverse weld specimen was used to prepare a 2- by 6-in. transverse bend specimen, in which the bending stress was applied transversely, perpendicular to the direction of welding. The advan-

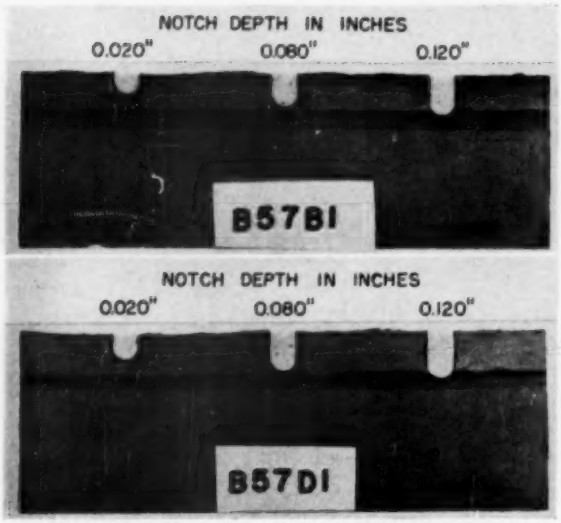

Fig. 6 Location of notches in weld cross section

tage of this specimen is that the notch is located wholly within the region being investigated. However, the direction of the applied stress is not in the direction in which the oriented microcracks would have the greatest effect, as is the case for the longitudinal bend specimens.

The weld-bead bend specimens were saw-cut to the nominal dimensions of 2 by 6 in. No further machining was performed on the surfaces of the specimens, so that the dimensions of length and width were accurate only to about $^1/_{16}$ in. The top and bottom surfaces of the plate were as-rolled and the weld reinforcement was not removed.

In order to determine the properties of the weld at different locations in the weld cross sections, the bend specimens were notched to one of three depths with a milling cutter having a $^1/_8$ in. thickness and a $^1/_{16}$-in. radius cutting edge. The notches were located so that the base of the notch was either (1) at about the center of the weld metal (notched 0.020 in. below the surface of the plate), (2) slightly above the fusion line (notched 0.080 in. below the plate surface) or (3) in the heat-affected zone (notched 0.120 in. below the plate surface). Figure 6 shows the location of these notches in the weld cross sections.

As shown in Fig. 1, the longitudinal bend specimen was notched across the weld perpendicular to the direction of welding, and the transverse bend specimen was notched at the weld centerline parallel to the direction of welding. Only those specimens which were notched to within 0.003 in. of the desired depths are reported.

A series of plain plate specimens were sawed from the same material and notched to the same depths as the weld specimens. These specimens were useful in interpretating the test results as indicated below.

Bend Test Procedure

The 2- by 6-in. bend-test specimens were tested as simple beams on a $4^1/_2$-in. span with the weld bends in tension. A photograph of the test jig developed for this purpose is shown in Fig. 7. The tests were performed at approximately $-90°$ F in a bath of petroleum base solvent containing dry ice.

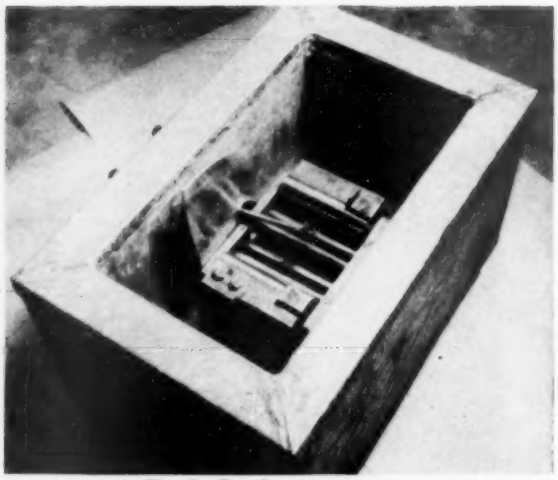

Fig. 7 Bend-test apparatus

To record the maximum deflection, a lever transmitted the deflection of the specimen through a sylphon bellows to a microformer located on the outside of the tank. The microformer activated a load-deflection recorder connected to a Baldwin 120,000-lb capacity hydraulic testing machine, which was operated at a strain rate of about 0.12 ipm. Because the range of the microformer was limited to about 0.33 in. of deflection, it was necessary to reset the microformer during the test. This was accomplished after reducing the load until the deflection of the specimen stopped.

It is possible that the maximum deflection might not be a true indication of the first crack in those cases in which the deflection was large (over 0.75 in.). This was indicated when a crack was discovered in a specimen which was removed from the test jig before final failure because the limit of the test jig had been reached. In addition, several of the specimens notched to a depth of 0.020 in. showed a drop in load of several hundred pounds before final fracture occurred. However, the results reported herein are presented in terms of the maximum deflection.

Interpretation of Weld-Bead Bend-Test Data

The test data were recorded directly in terms of deflection and load. These results provide a suitable means of comparison at any one notch depth, but do not allow a logical comparison of results at different notch depths because of the different geometries. To circumvent this difficulty, the results have been recalculated using the values of the plain plate tests to evaluate the effects of the different notch depths. That is, the deflection for a weld specimen notched to a particular notch depth is expressed as a per cent of the average maximum deflection of the plain plate specimens notched to the same depth as the weld specimen and subjected to the same heat treatment, effectively giving the weld a ductility rating, a common denomina-

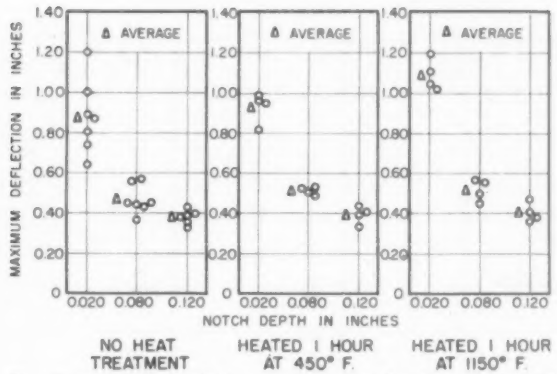
MAXIMUM DEFLECTION IN INCHES
Δ AVERAGE
NOTCH DEPTH IN INCHES
NO HEAT TREATMENT
HEATED 1 HOUR AT 450° F.
HEATED 1 HOUR AT 1150° F.

Fig. 8 Results of plain plate tests of Steel E, weld-bead series

tor by which the specimens notched to different depths are compared. An investigation of the validity of this method of interpretation is presented in the Appendix.

DISCUSSION OF WELD-BEAD BEND-TEST RESULTS FOR STEEL E

Plain Plate Specimens

The results of the plain plate tests of Steel E (ASTM Firebox Quality A285C) are presented in Fig. 8. For each heat treatment, there is a decrease in the maximum deflection with an increase in the notch depth, and for each of the three notch depths, there is an increase in ductility as the heat treatment progresses from no heat treatment to the preheat treatment to the postheat treatment. It appears that the heat treatments are more effective near the surface of the plate, and that the postheat treatment is more effective than the preheat treatment.

Effect of Quench Time on Specimens Notched in the Weld Metal

The results of the specimens without heat treatment notched in the weld metal are presented in Fig. 9. For the longitudinal E6010 weld specimens, there occurs a distinct reduction in the ductility rating at a quench time of 4 min after welding, which corresponds to a temperature of 300–320° F. With the exception of one specimen having gas pockets at the test section, there is no such decrease for the E6016 welds. These results are in essential agreement with those reported by Flanigan, Bocarsky and McGuire,[5] although the test specimens and the resultant levels of deflection are somewhat different.

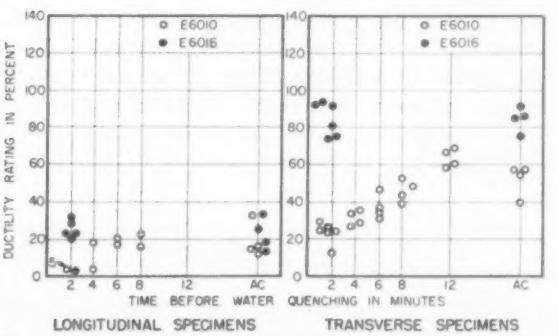

Fig. 9 Effect of quench time on weld-bead specimens of Steel E notched in the weld metal

For the transverse specimens, the ductility rating of the E6010 welds decreases gradually as the quench time decreases from 12 to 2 min after welding (230 to 260° F), whereas the ductility of the E6016 welds remains constant for the quench times employed. The greater ductility rating of the low hydrogen welds is probably a consequence of the greater strength and ductility of the weld metal as indicated by the all-weld-metal tensile tests.

Although the level of ductility rating is greater for the transverse specimens, the effects of the combination of high hydrogen contents and rapid low temperature cooling rates are detected by both the longitudinal and the transverse specimens, but the reduction in ductility rating with quench time occurs more abruptly for the longitudinal specimens. Note that this embrittlement in the weld metal is pronounced in the transverse specimens even though the orientation of the microcracks is parallel to the direction of the applied bending stress, their least detrimental orientation.

Weld-Bead Specimens Without Heat Treatment

The results for the longitudinal and the transverse weld specimens are presented in Figs. 10*A* and 10*B*, respectively.

A comparison of the quenched and the air-cooled longitudinal specimens without heat treatment again indicates the distinct embrittlement of the E6010 welds notched in the weld metal; at the other two notch depths, the E6010 welds are not embrittled by quenching. The comparison also indicates that the ductility of the E6016 longitudinal welds was not reduced by quenching the specimens notched 0.020 or 0.080 in. deep, but that quenching reduced the ductility at a notch depth of 0.120 in. The cause of this decrease in ductility in the heat-affected zone is not known.

There is a general increase in the ductility rating as the notch depth is increased for the air-cooled longitudinal welds deposited with both electrodes. For the quenched welds, however, the ductility rating remains about the same for the three notch depths with the exception of the embrittled, quenched high hydrogen welds notched in the weld metal. The low ductility of the specimens notched in the weld metal might be influenced by the low ductility of the material near the fusion line and in the heat-affected zone. The general low ductility rating for the longitudinal specimens indicates that although hydrogen embrittlement is detrimental, other effects of welding are perhaps more detrimental. A portion of this low ductility can be attributed to the geometrical effect of the weld reinforcement as discussed in the Appendix.

The results of the tests of the transverse weld speci-

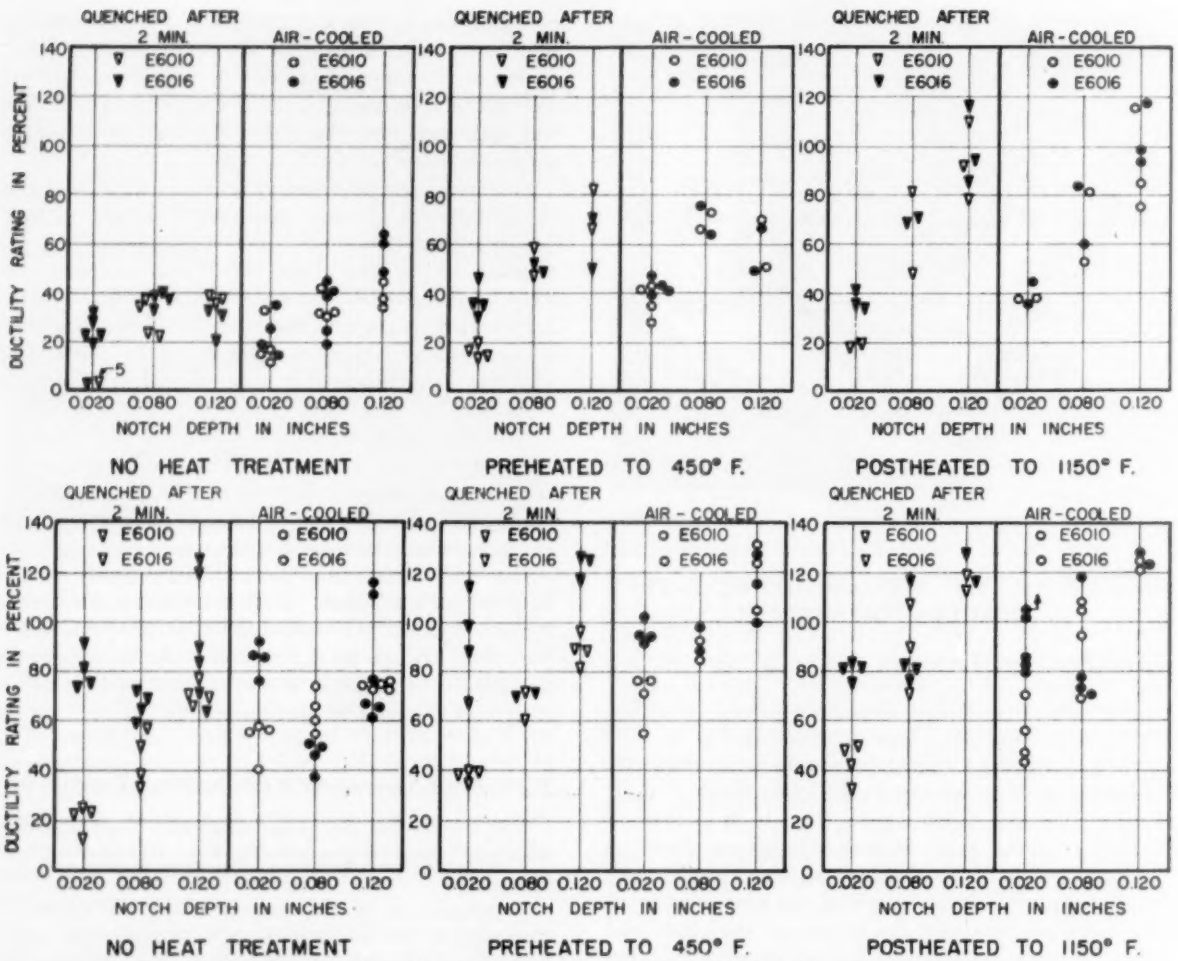

Fig. 10 Results of weld-bead tests of Steel E, upper longitudinal tests, lower transverse tests

mens without heat treatment indicate the characteristic embrittlement of the quenched E6010 weld metal, and the greater strength of the E6016 weld metal. The high hydrogen welds notched near the fusion line are more ductile than the low hydrogen welds in the air-cooled condition, but the reverse is true in the quenched condition. No explanation is given for these results. For the specimens notched in the heat-affected zone, no difference is noted for the welds deposited with the two types of electrode, and quenching has no effect on the ductility rating.

Comparison of the transverse welds notched to the three depths further emphasizes the detrimental action of embrittlement in the weld metal of the quenched E6010 weld beads, which have a ductility rating considerably less than any of the other transverse specimens without heat treatment. With the exception of the E6010 weld beads notched in the weld metal, the material near the fusion line has the lowest ductility rating.

Effect of Heat Treatments on Specimens Notched in the Weld Metal

(*a*) *Longitudinal Weld Specimens.* The preheat and the postheat treatments were about equally effective in increasing the ductility rating of the weld metal. Although the ductility ratings of the heat treated, quenched E6010 welds are as great as the air-cooled welds without heat treatment, embrittlement of the quenched specimens is as pronounced in the heat treated condition as for the specimens without heat treatment.

(*b*) *Transverse Weld Specimens.* The ductility rating of the E6016 specimens without heat treatment is about 90%, and is not significantly increased by heat treating. For the air-cooled E6010 welds, the ductility rating is not greatly improved by the heat treatments employed, whereas the quenched E6010 welds have a greater ductility rating when either preheated or postheated. Therefore, the effects of embrittlement in the weld metal are reduced by about an equal amount either by preheating or by postheating.

Effect of Heat Treatments on Specimens Notched Near the Fusion Line

(*a*) *Longitudinal Weld Specimens.* The air-cooled, preheated specimens and the air-cooled or the quenched, postheated specimens have about the same increase in

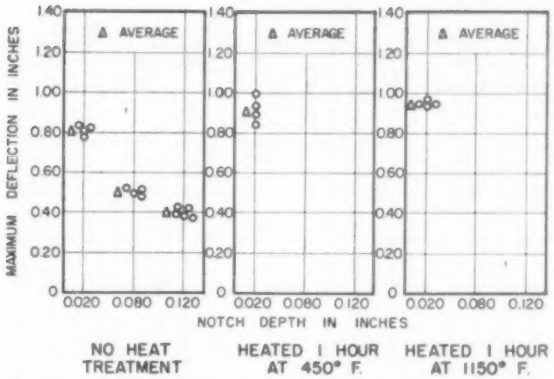
MAXIMUM DEFLECTION IN INCHES
Δ AVERAGE
NOTCH DEPTH IN INCHES
NO HEAT TREATMENT
HEATED 1 HOUR AT 450° F.
HEATED 1 HOUR AT 1150° F.

Fig 11 Results of plain plate tests of Steel B, weld-bead series

ductility rating; however, the quenched, preheated specimens have an increase in ductility rating only about half as great. Thus, there is an indication of embrittlement caused by quenching for the preheated specimens, but not for the postheated specimens.

(*b*) *Transverse Weld Specimens.* In the heat-treated conditions, the E6010 and the E6016 types of weld metal have the same ductility ratings. The postheat treatment is equally effective for the air-cooled and the quenched welds, whereas the preheat treatment is effective for the air-cooled welds, but relatively ineffective for the quenched welds. Thus, as for the longitudinal specimens, the transverse preheated welds show an indication of embrittlement caused by quenching, whereas no embrittlement is noted for the postheated specimens.

Effect of Heat Treatments on Specimens Notched in the Heat-Affected Zone

(*a*) *Longitudinal Weld Specimens.* For the longitudinal welds notched in the heat-affected zone, the postheat treatment is significantly more effective than the preheat treatment, especially for the air-cooled welds, in which case preheating may be beneficial only for the E6010 specimens.

(*b*) *Transverse Weld Specimens.* For the transverse welds, both heat treatments increase the ductility rating to a value greater than 100%, except for the quenched, preheated E6010 welds which have a rating less than 100%. Thus, the postheat treatment appears more certain to increase the ductility rating than the preheat treatment; however, it should be noted that even without heat treatment, the ductility ratings are about 80% for all of the transverse welds.

DISCUSSION OF WELD-BEAD BEND-TEST RESULTS FOR STEEL B

Plain Plate Specimens

Steel B (ASTM A7) was tested without heat treatment at the three notch depths and in the preheated

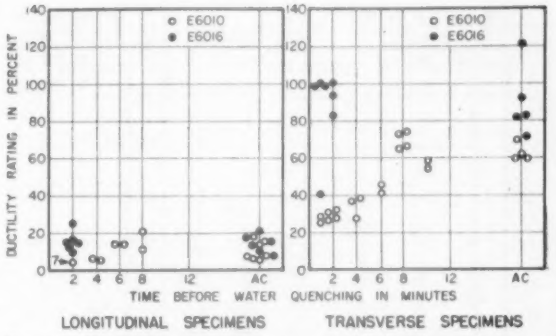

Fig. 12 Effect of quench time on weld-bead specimens of Steel B notched in the weld metal

and the postheated conditions at a notch depth of 0.020 in. The results of the plain plate bend specimens, Fig. 11, are not greatly different from the results for Steel E.

Effect of Quench Time on Specimens Notched in the Weld Metal

For the 0.020-in. notch depth, the results of the specimens without heat treatment are presented in Fig. 12.

All of the longitudinal specimens had a very low ductility rating (less than 20%). Embrittlement of the high hydrogen E6010 welds caused by quenching is evidenced for quench times of 4 min or less. In the air-cooled condition, there does not appear to be a consistent difference in the ductility of the E6010 and the E6016 welds.

The tests of the transverse specimens notched 0.020 in. deep indicate a more pronounced embrittlement caused by quenching than do the tests of the longitudinal specimens. The low-hydrogen welds retain their ductility as the severity of the quench is increased (except for one specimen), whereas the rating of the E6010 welds drops gradually as the quench time is decreased below 8 min after welding. In the air-cooled condition, the greater ductility of the low-hydrogen welds again can be attributed to the greater strength and ductility of the low-hydrogen weld metal.

Welds Without Heat Treatment

A significant result of the longitudinal bend tests, plotted in Fig. 13*A*, is that the quenched E6010 welds have a lower ductility rating than the E6016 welds at all three notch depths. As noted above, the E6010 welds notched 0.020 in. deep are embrittled by quenching. For the specimens notched 0.080 in. deep, the rating of the E6016 welds is not affected by quenching, whereas the E6010 welds may show some reduction in ductility due to quenching. At the 0.120-in. notch depth, neither type of weld is affected by quenching. A comparison of the results at the three notch depths indicates that the longitudinal specimens notched 0.020 in. deep have the lowest ductility rating, and that the embrittlement of the quenched E6010 weld metal is

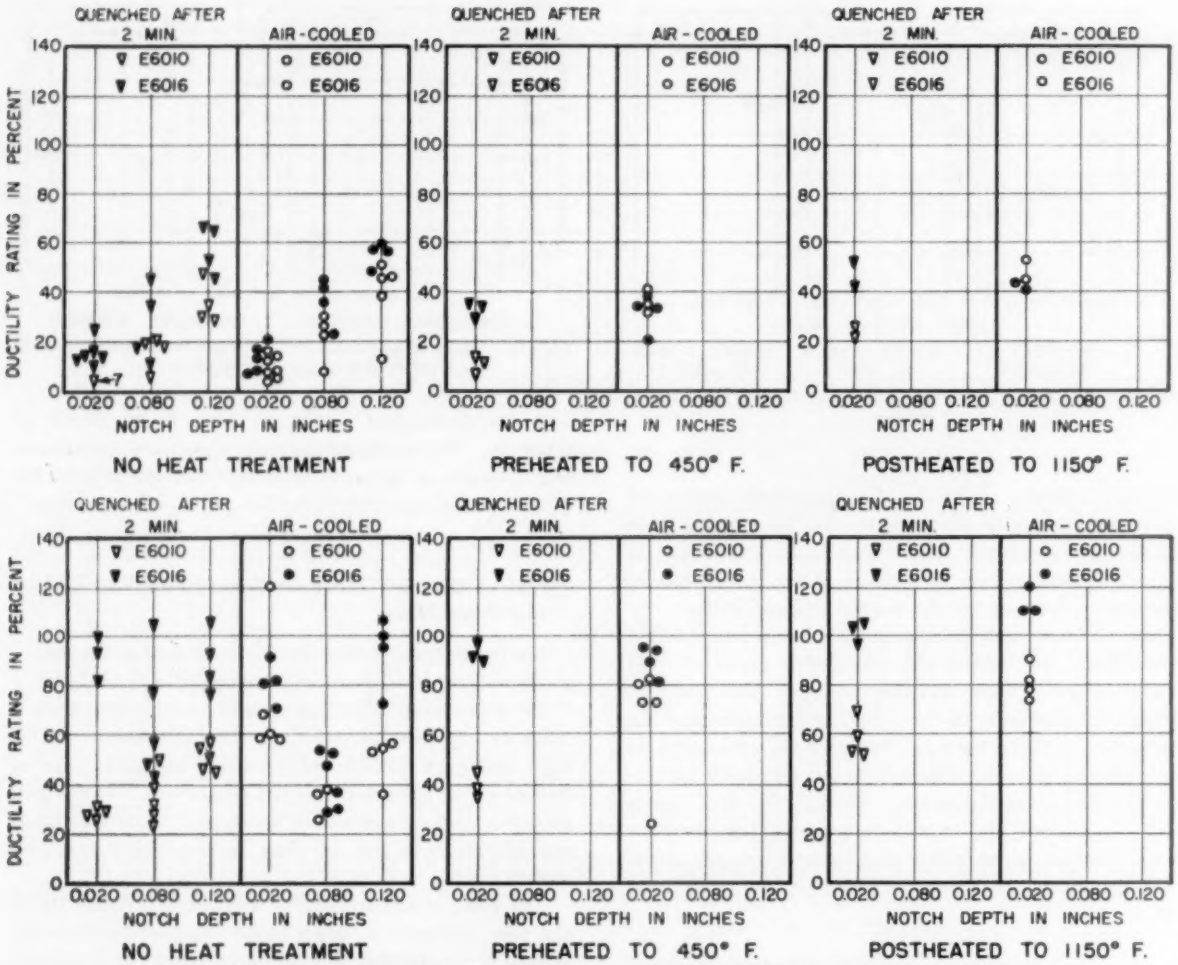

Fig. 13 Results of weld-bead tests of Steel B, upper longitudinal tests, lower transverse tests

especially detrimental because of the already low level of ductility.

For the transverse welds, Fig. 13*B*, the embrittlement caused by quenching is indicated for the welds notched in the weld metal. In addition, the greater ductility rating of the low-hydrogen welds at all three notch depths is apparent, although not as pronounced for the welds notched near the fusion line. For the transverse welds not subject to hydrogen embrittlement, the general level of ductility rating for the specimens notched near the fusion line is significantly less than at the other two notch depths. For the quenched E6010 welds, hydrogen embrittlement reduces the ductility rating of the weld metal to that of the material near the fusion line.

Effect of Heat Treatments on Specimens Notched in the Weld Metal

(*a*) *Longitudinal Weld Specimens.* Both the preheat and the postheat treatments increased the ductility rating, the postheat treatment being about twice as effective as the preheat treatment. Although the level of ductility is raised by the heat treatments, the effect of quenching the E6010 weld metal is as pronounced as for the specimens without heat treatment.

(*b*) *Transverse Weld Specimens.* For the transverse specimens, the greatest effect of the heat treatments is to increase the ductility rating of the quenched E6010 specimens notched in the weld metal. There is some improvement in the ductility rating for the air-cooled E6010 specimens, but little improvement is noted for the E6016 specimens, which have a rating of 100% without heat treatment. As in the longitudinal specimens, the postheat treatment is more effective than the preheat treatment. The evidence of embrittlement for the quenched E6010 welds is reduced by the heat treatments.

DISCUSSION OF WELD-BEAD BEND-TEST RESULTS FOR STEEL D

Plain Plate Specimens

All of the specimens from Steel D (ASTM A242) were welded without heat treatment. The results for

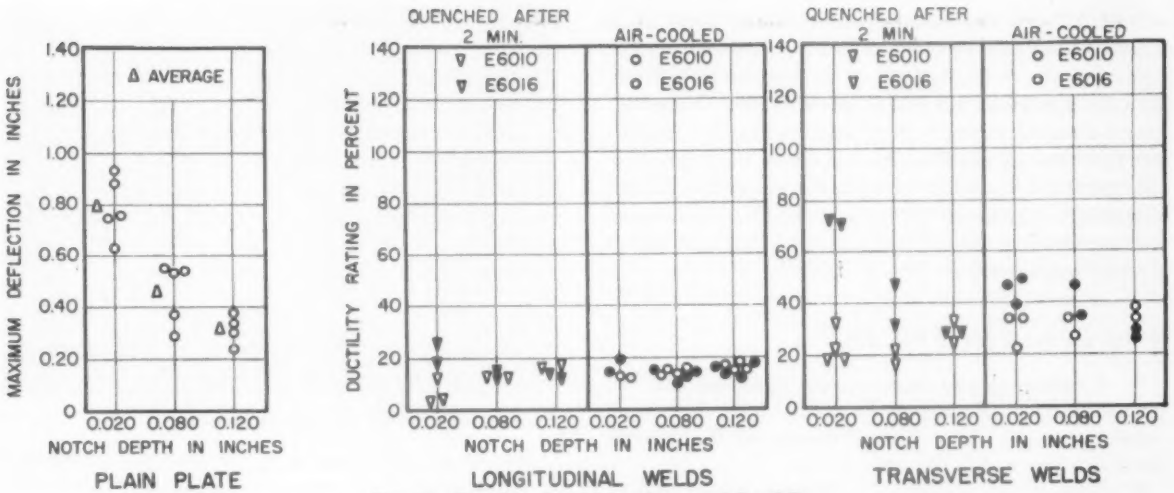

Fig. 14 Results of weld-bead tests of Steel D

the plain plate specimens, Fig. 14, show that the trend of the results is similar to those found for Steels E and B.

Welds Without Heat Treatment

The results for the weld specimens are presented in Fig. 14. For the longitudinal specimens, the most important feature of the results is the very low level of the ductility rating at all three notch depths. Thus, the effects of welding are extremely detrimental and are more pronounced for this particular steel than for the plain carbon steels. The embrittlement of the quenched, high-hydrogen specimens notched in the weld metal is especially harmful because of the already low level of ductility rating. It is possible that the low ductility at the 0.020-in. notch depth is influenced by the low ductility of the material at the deeper notch depths.

The transverse specimens also indicate a lower ductility rating than the plain carbon steels. At a notch depth of 0.020 in., the low-hydrogen welds have a higher ductility rating than the high-hydrogen welds, which are embrittled slightly by quenching. The low-hydrogen welds have a greater ductility rating for the specimens notched near the fusion line; the rating of the high-hydrogen welds is again decreased with water quenching. For the specimens notched in the heat-affected zone, little difference can be detected between the welds produced with the two electrode types or subjected to the two cooling conditions.

The most important result of the tests of this steel is the indication of the detrimental effect of welding independent of the embrittlement of the E6010 weld metal.

CONCLUSIONS

1. The ductility of bead-on-plate welds deposited with the "high hydrogen" E6010 electrode notched in the weld metal is reduced by rapid low-temperature cooling rates at temperatures as low as 249° F. This reduction in ductility appears to be associated with the occurrence of microcracks in the quenched high-hydrogen weld metal, although other factors might contribute. The ductility is reduced for E6010 welds stressed parallel to or perpendicular to the direction of welding. The weld metal deposited with the low-hydrogen E6016 electrode is not subject to this embrittlement after quenching.

Welds on Steel E (ASTM Firebox Quality A285C)

2. Hydrogen embrittlement of the longitudinally stressed E6010 welds occurs for rapid low-temperature cooling rates at temperatures as low as 320° F; the transverse welds are embrittled for rapid low-temperature cooling rates at temperatures as low as about 230° F.

3. The greater ductility of the air-cooled transverse low-hydrogen welds notched in the weld metal is probably a consequence of the greater tensile strength and ductility of this type of weld metal.

4. The embrittlement of the E6010 weld metal under conditions of rapid low-temperature cooling rates is not alleviated by preheating to 450° F or by postheating to 1150° F. However, the level of ductility is increased by the heat treatments so that the heat-treated, quenched welds notched in the weld metal have about the same ductility rating as the air-cooled welds without heat treatment.

5. For the longitudinally stressed welds, the postheat treatment generally increases the ductility more than the preheat treatment for specimens notched near the fusion line or in the heat-affected zone. For the transversely stressed welds, the postheat treatment is more effective than the preheat treatment for the quenched welds (except for the low-hydrogen welds notched in the heat-affected zone which are equally

benefited by either heat treatment), but both heat treatments are equally beneficial for the air-cooled welds.

6. For the welds stressed in the longitudinal direction, the specimens notched in the weld metal have the lowest ductility rating with or without heat treatment. For the welds stressed in the transverse direction, the specimens notched near the fusion line have the lowest ductility rating, except for the quenched high-hydrogen welds notched in the weld metal, which generally have a somewhat lower ductility rating.

Welds on Steel B (ASTM A7)

7. Cooling rates at temperatures as low as 320° F for the longitudinal specimens and 240° F for the transverse specimens cause embrittlement of the E6010 specimens notched in the weld metal.

8. Preheating to 450° F or postheating to 1150° F does not eliminate the effects of hydrogen embrittlement in the weld metal. However, the level of ductility is considerably raised by the heat treatments for the specimens stressed in the longitudinal direction. In the transverse direction, only the E6010 welds are improved; the E6016 welds without heat treatment are almost as ductile as the plain plate specimens.

9. For welds without heat treatment, the longitudinal welds notched in the weld metal have the lowest ductility rating, whereas the transverse welds notched near the fusion line have the lowest ductility rating, except for the embrittled E6010 welds notched in the weld metal.

10. The ductility ratings of the E6016 weld specimens notched in the weld metal, near the fusion line, or in the heat-affected zone are greater than the ductility ratings of the E6010 welds notched to the same locations.

Welds on Steel D (ASTM A242)

11. Steel D, a low-alloy high-tensile steel, is more adversely affected by welding than the other two steels tested, especially for the welds stressed longitudinally to the direction of welding.

12. Embrittlement is noted for the quenched E6010 weld metal stressed parallel or perpendicular to the direction of welding, but is not as pronounced as for Steels B and E. Some of the effect of this embrittlement might be masked by the general low ductility of welds on Steel D.

ACKNOWLEDGMENT

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The metallurgical studies were performed in the laboratories of the Department of Mining and Metallurgical Engineering, University of Illinois, under the supervision of W. H. Bruckner, Research Associate Professor of Metallurgical Engineering.

Appendix: Effects of Specimen Geometry

Object and Scope of Investigation

Two questions of major importance are considered in this study of the effects of geometry. The first was to determine what proportion of the reduction of bend properties of the welded specimens, as compared to the plain plate specimen, was a result of metallurgical changes and what proportion was a result of the effect of the geometry of the weld reinforcement projecting above the surface of the plate. The second problem was the verification of the method of interpreting the bend test results obtained from bead-on-plate welds notched to different depths.

In order to fulfill these objectives, the results from three series of bend tests have been utilized: the weld-bead series, the simulated-bead series and the machined-weld series. The simulated-bead series is employed to evaluate the effect of the weld reinforcement on the bend properties; the method of interpretation of the test results is studied by comparing the results of the weld-bead series (discussed in the paper) and the machined-weld series.

SIMULATED-BEAD TESTS

Details of Simulated-Bead Tests

The purpose of the simulated-bead tests was to determine the effects of the weld reinforcement on the bend test properties of notched bead-on-plate bend specimens. This objective was fulfilled by testing a bend specimen which was machined so as to have a geometry simulating, as nearly as possible, that of the weld bead reinforcement. It is emphasized that these specimens did not contain a weld; the metallurgical properties were those of the plate material, whereas the geometrical characteristics were those of a machined, simulated weldbead. Thus, the geometrical effect is evaluated by isolating it from the metallurgical variables of welding.

The steel used for this series of tests was from the same heat as the B steel of the weld-bead series. However, the simulated-bead specimens were machined from a 1-in. plate, whereas the previously discussed weld-bead specimens were prepared from $^{3}/_{4}$-in. plates. As noted in Table 1, the yield point and the maximum

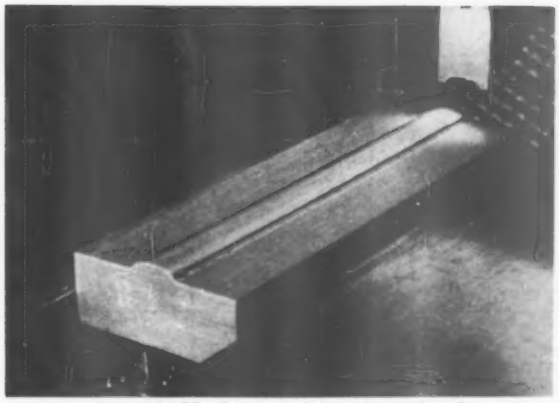

Fig. 15 Machining of simulated-bead

strength of the 1-in. plate was somewhat greater than that of the $^3/_4$-in. plate.

All of the surfaces of the simulated-bead specimens were machined to close tolerances, the final dimensions being the same as the nominal dimensions of the weld-bead specimens shown in Fig. 1. A photograph of the machining of a simulated bead is shown in Fig. 15. A $^1/_8$-in. thick milling cutter having a $^1/_{16}$-in. radius cutting edge was used to notch the specimens to a depth of 0.020, 0.080 or 0.120 in. below the machined plate surface.

A series of simulated-bead plain plate specimens having the same overall machined dimensions as the simulated-bead specimen, but not containing the simulated bead, were used to evaluate differences in the bend properties of the base metal through its thickness and to compare the results of the weld specimens notched to different depths.

Results of Simulated-Bead Tests

The results of the simulated-bead tests are presented in Fig. 16. For the longitudinal specimens, the results, expressed as a percent of the maximum deflection of the corresponding simulated-bead plain plate specimens notched to the same depth, indicate an almost linear increase in the ductility rating (from 60 to 100%) with increasing notch depth. For the transverse specimens, the results are similar to those of the longitudinal specimens. However, the effect of the external geometry is seen to be less than in the case of the longitudinal specimens, the ductility rating increasing from 80 to 100%.

It is apparent that the geometrical effect of the weld bead accounts for a significant portion of the reduction in ductility of the bead-on-plate bend specimens notched in the weld metal, but that the geometry of the weld bead has no effect on the bend-test properties of specimens having a notch depth equal to or greater than 0.120 in. below the surface of the plate.

THE MACHINED-WELD SERIES

Details of Machined-Weld Series

The second problem considered in the geometry studies was the validity of the method of interpretation of the weld-bead test based on rating the maximum deflection of the notched bead-on-plate bend specimens as a percent of the maximum deflection of the plain plate bend specimens notched to the same depth (the ductility rating). This problem is studied by comparing the results of the machined-weld series with those of the weld-bead series, reported in the main investigation.

The welding procedures used in the preparation of the machined-weld specimens were the same as those employed for the weld-bead series and the bend specimens were machined from the same locations in the weldments. However, the surfaces of the machined-weld specimens received sufficient machining to make the final test specimen geometry identical for specimens having the base of the notch located 0.020, 0.080 or 0.120 in. below the *original* plate surface.

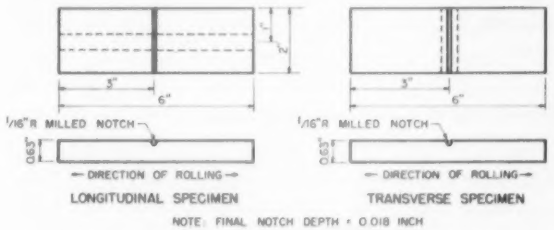

Fig. 17 Details of machined-weld specimens

Figure 17 shows the details of the final bend-test specimen and gives the machining tolerances. Note that the weld specimens and the plain plate specimens of the machined-weld series differ from those of the weld-bead series in only two respects: (1) the thickness of the machined-weld bend specimen is 0.630 in., whereas the weld-bead bend specimen has a nominal as-rolled thickness of $^3/_4$ in. and the mill

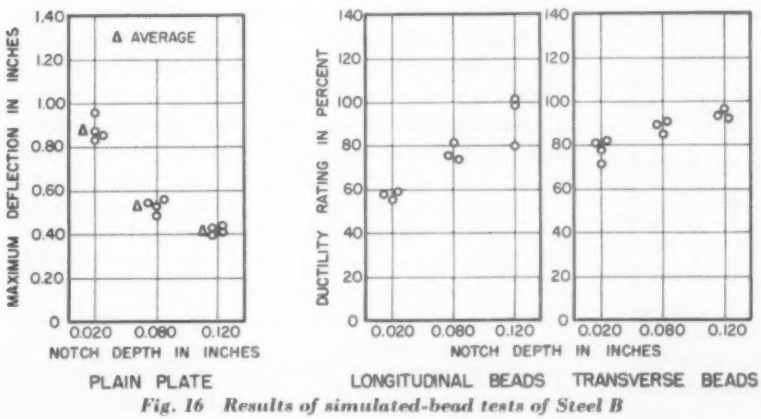

Fig. 16 Results of simulated-bead tests of Steel B

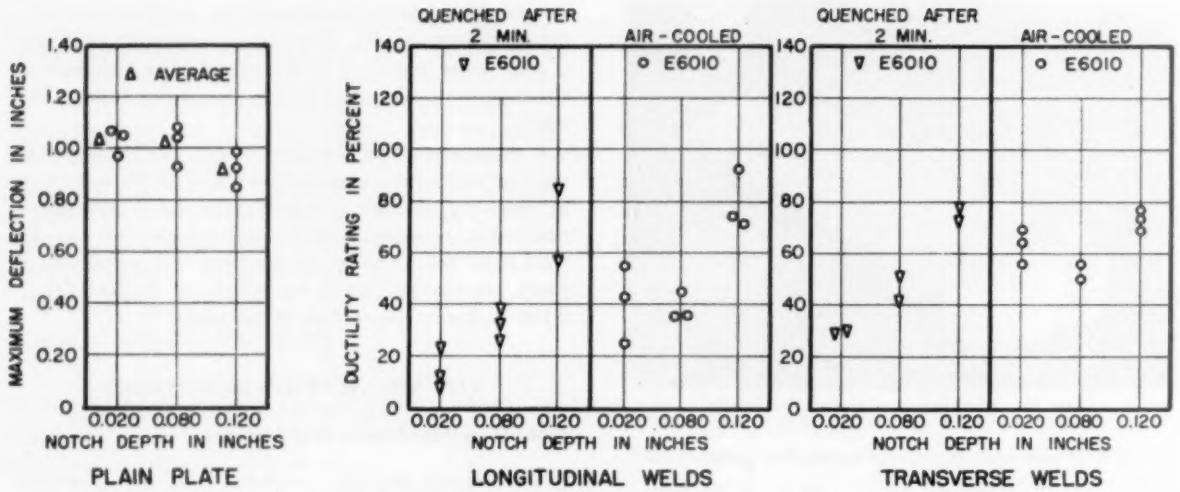

Fig. 18 Results of machined-weld tests of Steel B

scale and the weld reinforcement are not removed. The 0.630 in. thickness was chosen because it was the largest dimension which allowed a constant geometry for specimens having the base of the notch located in the weld metal, near the fusion line, or in the heat-affected zone.

(2) The final depth of the notch is 0.018 in. for all of the machined-weld bend specimens as contrasted to the 0.020, 0.080 or 0.120-in. notch depths of the weld-bead bend specimens. For the machined-weld specimens notched 0.020 in. below the *original* plate surface, 0.002 in. was removed from the top surface; for the specimens notched 0.120 in. below the *original* plate surface, 0.102 in. was removed from the top surface. The amount of material removed from the bottom surface was dependent upon the as-rolled thickness of the plate.

Results of Machined-Weld Tests

The test results of the machined-weld specimens are presented in Fig. 18. The machined-weld plain plate tests show that there was little difference in the plate properties at the different locations in the thickness of the plate. Since differences in geometry are practically nonexistent for the machined-weld specimens notched to different depths below the original plate surface, the machined-weld specimens having the base of the notch located at different regions of the weld cross section could be compared directly in terms of the maximum deflection. However, the results are expressed in terms of the percent of the plain plate maximum deflection (the ductility rating) for convenience in comparison with the plotted results of the weld-bead series.

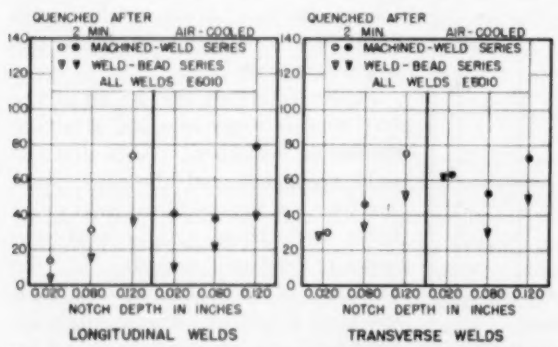

Fig. 19 Comparison of average results of weld-bead and machined weld tests of steel B

In order to compare the weld-bead and the machined-weld series of tests, the average results have been replotted, in Fig. 19, in terms of the ductility rating. Remember that the weld-bead specimens have the weld reinforcement on; hence, there is a difference in geometry between the weld specimens and the plain plate specimens.

A comparison between the results of the longitudinal machined-weld and weld-bead series indicated a general agreement in the trend of the results, with the greatest divergence occurring in the relative ductility ratings of the air-cooled specimens notched 0.020 and 0.080 in. deep, in which case the machined-weld tests do not indicate the same decrease in ductility rating as the weld-bead tests.

For the transverse tests, the agreement in the trend between the ductility ratings of the machined-weld and the weld-bead tests is even closer than in the case of the longitudinal tests. A comparison of the results from the longitudinal and the transverse tests indicates that, in general, the ductility rating of the transverse specimens is greater than that of the longitudinal specimens for both the machined-weld and the weld-bead series.

In general, the ductility rating of the machined-weld specimens is somewhat greater than that of the weld-bead tests, especially for the deeper notch depths. With the exception indicated above, the trend of the results is significantly the same for the machined-weld and the weld-bead series.

From these comparisons, it may be concluded that the interpretation of the bead-on-plate bend tests can

be based on rating the maximum deflection of the weld specimens as a percent of the maximum deflection of their respective plain plate specimens (the ductility rating).

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Tension, Shear and Impact Strengths of Spot-Welded Titanium Joints

Physical properties necessary for the design of spot welded joints in commercially pure titanium sheet

by M. L. Begeman, E. H. Block, Jr. and Frank W. McBee, Jr.

SPOT welding of commercially pure titanium has been the subject of much research with the result that it is generally conceded that this form of welding is successful. The information, however, on the properties of spot-welded sheet materials necessary for the satisfactory application of this process, has been lacking. An effort was made in the following investigation to obtain more data concerning those physical properties necessary for the design of spot welded joints. Various tests were conducted to provide accurate information as to the tension, shear and impact strengths of commercially pure titanium sheets.

MATERIALS USED IN TEST

The basic material used in the following tests was commercially pure titanium, designated Ti75a and produced by the Titanium Metals Corporation of America. For the most part 22-gage (0.031-in.) material was used; however, limited tests were made using 24- and 25-gage material. As supplied, the material was in an annealed condition having the following specified physical properties:

Hardness, R_b	85–95
Ultimate strength, psi	75–100,000
Yield strength, psi	60–90,000
Elongation, %	20–25

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Prior to welding, the sheet stock was sheared into test coupons $^3/_4$ x 2 $^3/_4$ in. which were degreased with carbon tetrachloride. Welds were made using a $^3/_4$-in. lap in all specimens tested in shear: cross specimens were used in all tension tests.

EQUIPMENT USED IN INVESTIGATION

All welding performed in this investigation was accomplished on an Acme 75-kva pressure-type machine in conjunction with a General Electric synchronous control panel. Current values were measured with a calibrated manganin shunt in the secondary of the welding transformer, using a Land camera and cathode-ray oscilloscope to obtain actual values. The welds were made with Mallory No. 1527 (fluted RWMA Class II) electrodes having a 2-in. radius dome. These tips were cooled with tap water at a rate of 1.5 gpm.

A Southwark Tate Emery Universal Testing Machine was used to load all specimens tested under static load. Tension-shear specimens were held with Templin Sheet metal grips, while the direct tension specimens were held in the fixture as shown in Fig. 1 (*a*). This fixture was designed to conform with the standard RWMA cross-tension fixture except for the fact that the components tested were only $^3/_4$ in. wide and 2 $^3/_4$ in. long. Alignment of the fixture was effected by the use of two ball-ended screws which attached the fixture to the testing machine. Specimens were loaded to complete failure under a constant load condition.

Impact tests were made on a Tinius Olsen pendulum-type impact machine using special holding fixtures for each of the two tests. For the tension impact tests cross-welded specimens were mounted in the fixture shown in Fig. 1 (*b*). The fixture, shown in Fig. 1 (*c*), was designed to test shear impact specimens. Results

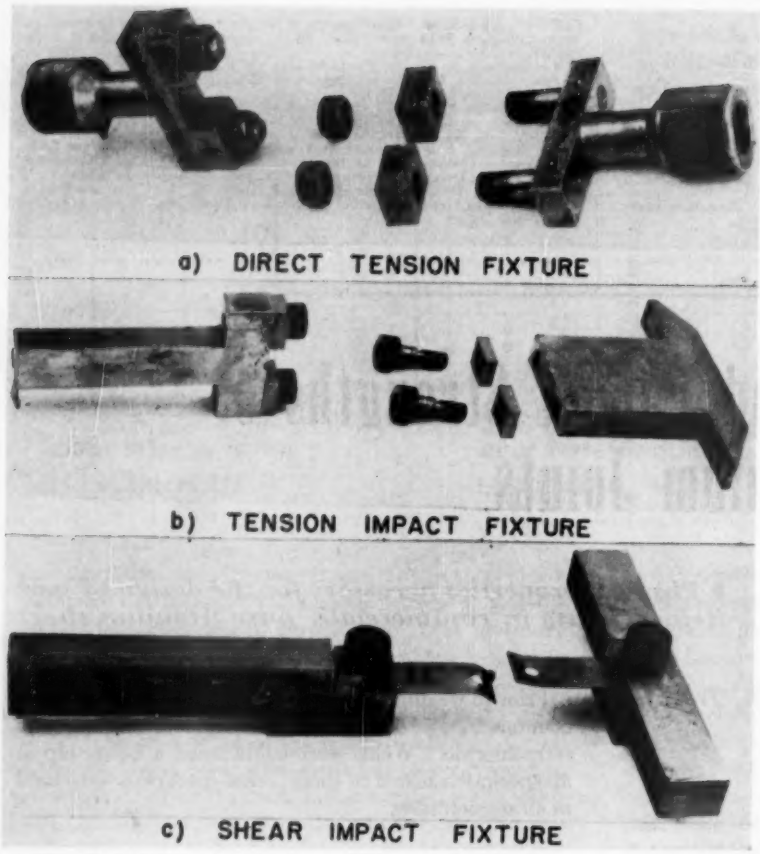

Fig. 1 Fixtures for holding specimens in tension and impact tests

from the shear impact may be subject to some possible error since the specimen was rather long and some energy was expended in stretching the specimens slightly.

PROCEDURE

Information obtained in previous investigations for spot welding titanium 75a was used in setting up conditions for these tests. All welds were made using the following conditions: squeeze time, 20 cycles; hold time, 20 cycles; electrode closing rate, 3 fps; throat depth, 12 in.; horn gap, 8 in.; tip pressure, 600 lb; and electrode stroke, 0.25 in.

Weld time and weld current were considered to be major variables; these conditions were varied to extremes in each direction. Each set of conditions involved making three test specimens for each type of loading as well as one for metallurgical examination. Indentation was measured on each of the specimens. Penetration, hardness, weld diameter and weld structure were observed from examination of the mounted and etched metallurgical specimen. Destructive tests were then made to obtain strengths for tension shear, direct tension, etc. The average of the three specimens was used in plotting all curves.

EFFECTS OF WELD CURRENT

Weld Strength

Tension-shear and direct tension strengths are both shown in Fig. 2 for variable weld current and for various weld times. As can be seen from the curves, weld strength in both cases increases moderately both with weld current and weld time. The range of current used represents approximately the extremes which can be used for this material. Lower values result in a decrease of the weld strength while higher values cause flashing and excess indentation. The curves emphasize the wide welding range of this material without much change in weld strength for a given weld time. If static strength is of primary concern there is no appreciable gain from exceeding weld current and weld time setting of 8000 amp and 12 cycles, respectively.

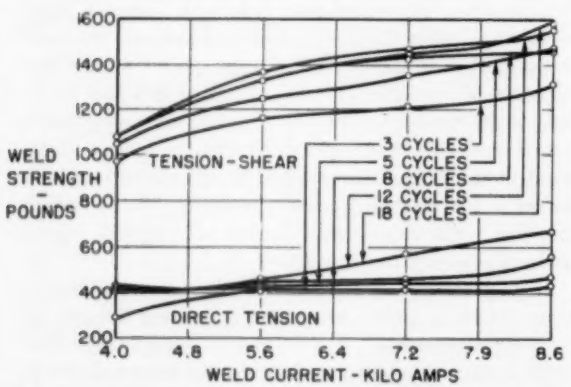

Fig. 2 Tension-shear and direct tension strengths for variable weld current at various weld times

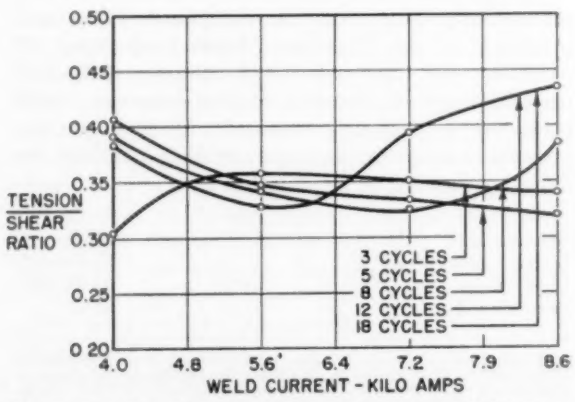

Fig. 3 Tension shear ratios for Ti75a spot-welded joints

Tension Shear Ratio

If the ratios of direct tension strength to tension-shear strengths of the various points in Fig. 2 are made and plotted, values are obtained as shown in Fig. 3. These curves do not all follow the same trend, probably due to insufficient data on certain points and the sometimes erratic properties of titanium in general.

Since commercially pure titanium is considered to be a nonheat-treatable material, no preheating, postheating or furnace annealing was used. It was hoped that the longer weld times would, as is the case with most steels, effect a more ductile weld with a consequent increase in the ratio. In analyzing the information obtained the highest ductility ratio was 0.47, while the lowest was 0.31; an average of all values obtained was 0.36. This indicated that neither current nor weld time has any marked effect upon tension-shear ratios. As will be pointed out later there was very little change in weld hardness in any case. Hardness being a measure of ductility, this would indicate that little change in ductility ratio could be expected.

The average value of 0.36 is low for a ductile weld when considering that SAE 1020 steel has an average ratio of 0.50. Titanium Ti75a appears to have the general physical characteristics of spot welded SAE 1035 steel when the welds are subjected to postheat tempering during the welding process. Both materials have a high tension-shear strength, a relatively high direct tension strength and a tension-shear ratio of about 0.35. Aluminum 24ST also has a ratio in the order of 0.35.

Generally speaking a material which is cold rolled to obtain higher strength is not considered in its most ductile form. Apparently this is the case with Ti75a.

Table 1 shows ratios for 24- and 25-gage materials which results are essentially the same as for 22-gage material.

Table 1

Material	*Ratio: Direct Tension/ Tension Shear*	*Tension Impact*	*Shear Impact*
Ti75a, 24-gage, 4-cycle, 5.6-Kilo amp	0.31	5.4	7.3
Ti75a, 25-gage, 4-cycle, 4.8-Kilo amp	0.31	4.0	6.4

Impact Strength

The curves shown in Figs. 4 and 5 indicate the effect of varying the magnitude of the current on tension and shear impact strength for various cycle times. In both curves the trend is the same; the ability of the weld to absorb energy increasing with the current input. This increase is controlled by the fact that as more heat is put into the weld a larger diameter weld nugget is formed. Other possible factors, such as weld hardness or ductility and grain structure, are not believed to be controlling factors in this case because of their uniformity throughout the tests.

The extremely high values of shear impact shown for 12 and 18 cycles are due to the fact that the sheet width was too small for the large diameter welds obtained under these conditions. Failure occurred by tearing the sheet rather than the pulling of a plug in the normal fashion.

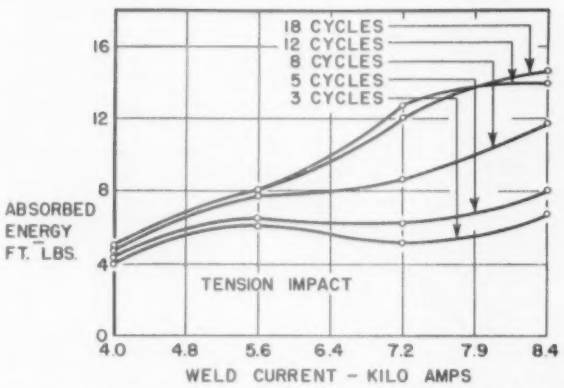

Fig. 4 Tension impact strength for spot-welded Ti75a

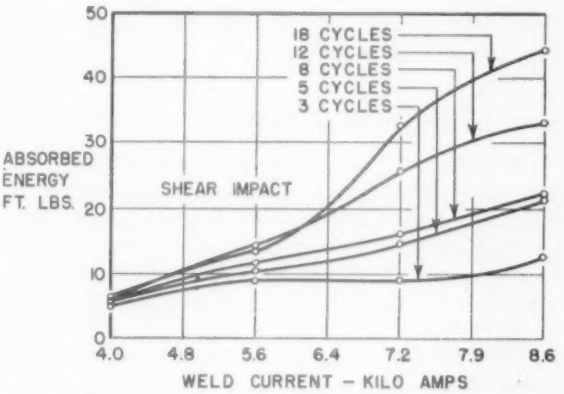

Fig. 5 Shear impact strength for spot-welded Ti75a

Indentation

The effect of the weld current upon the indentation of the welding electrodes into the base sheets is shown in Fig. 6. Since probably the largest potential application of spot-welded titanium sheet is in the aircraft industry and since excessive indentation of spot welds on the surface of a skin section has considerable detrimental effect upon the aerodynamic qualities of the section, it is felt that indentation is of prime interest in the spot welding of titanium.

It is not directly apparent from Fig. 6 that indentation will ever approach a limiting value; however, such is the case. A weld current slightly in excess of 8600 amp was found to produce expulsion of metal from the weld zone for all values of weld time which were used. For this reason the maximum practical weld current would probably be found to be something less than 8600 amp. On this basis it can be seen from examination of Fig. 6 that indentation is not likely to exceed five

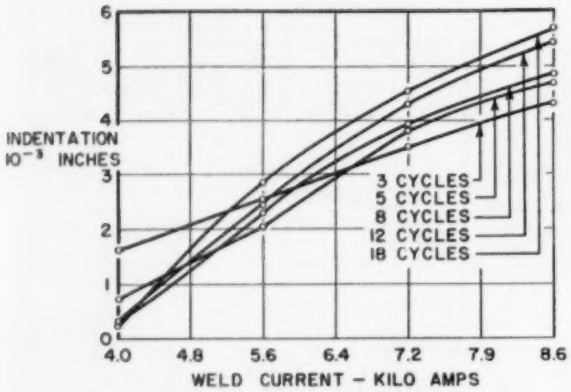

Fig. 6 Weld indentation in spot-welded Ti75a

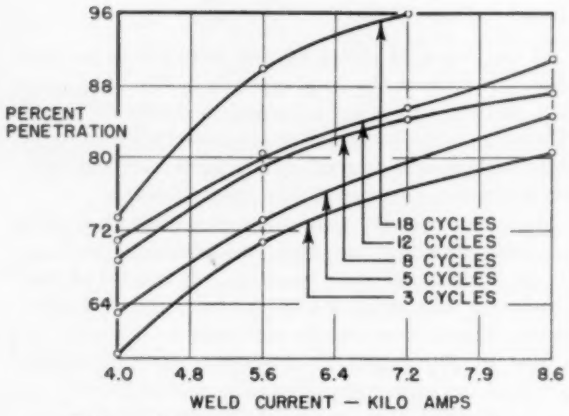

Fig. 8 Weld penetration in spot-welded Ti75a

thousandths which is less than 8% indentation of the base sheets and quite acceptable.

Nugget Diameter and Penetration

The diameter of the weld nugget as it is affected by the welding current is shown in Fig. 7. The trend of all of the curves is in line with those obtained in spot welding other metals. As more heat is put into the weld there is an increase in the nugget diameter which results in a stronger weld. The limiting factors, for a given set of conditions, are the electrode diameter and shape, indentation and penetration. The nugget diameter obtained for optimum condition is a compromise of these factors and the current.

Penetration, as computed from welds made in these tests, is based upon the indented weld thickness rather than upon the thickness of the two welded sheets. This definition, which differs from that of some investigators, has little effect upon the trend shown in Fig. 8, but the percent penetration values are greater. It can be observed from a study of this curve and preceding curves that the weld conditions which produce penetrations that would be considered excessive in other materials, produce welds in this alloy that have excellent physical properties. It is felt that, for this metal, penetration has no particular significance in thin sheets in so far as specification of a maximum permissible value is concerned.

EFFECT OF VARYING WELD TIME

The effect of varying weld time upon the weld strength (Fig. 9) is similar to that obtained by varying the current as was illustrated in Fig. 2. Results of these tests indicate that there is a slight gain in strength as the weld time is increased for most current settings. Apparently the time during which current flows can be varied over quite a wide range. The value selected will depend largely on the current value used—for low current settings more time is required. Results of these tests indicate that from 5 to 12 cycles represents good practice for optimum current setting.

TYPE OF FAILURE

Reference to Fig. 10 shows how the type of failure obtained in these tests was influenced by the welding current used and the time it was applied. In all of the figures there are typical specimens from each of the four tests. Both specimens in Fig. 10 (*a*) tested for shear indicate a typical shear failure while the two tested in tension have a plug type failure within the weld nugget.

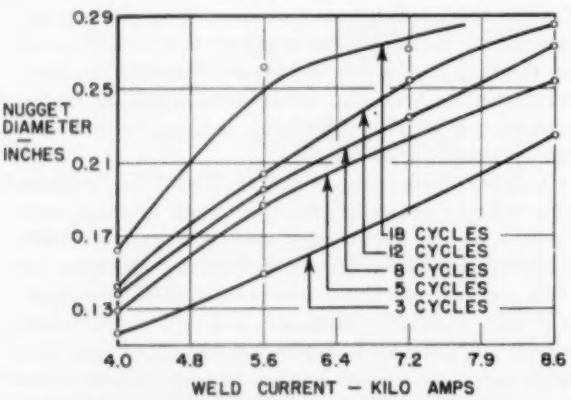

Fig. 7 Weld nugget diameter in spot-welded Ti75a

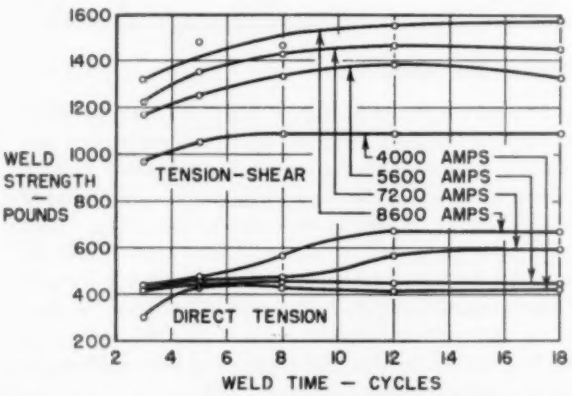

Fig. 9 Effect of varying weld time upon weld strength of spot-welded Ti75a

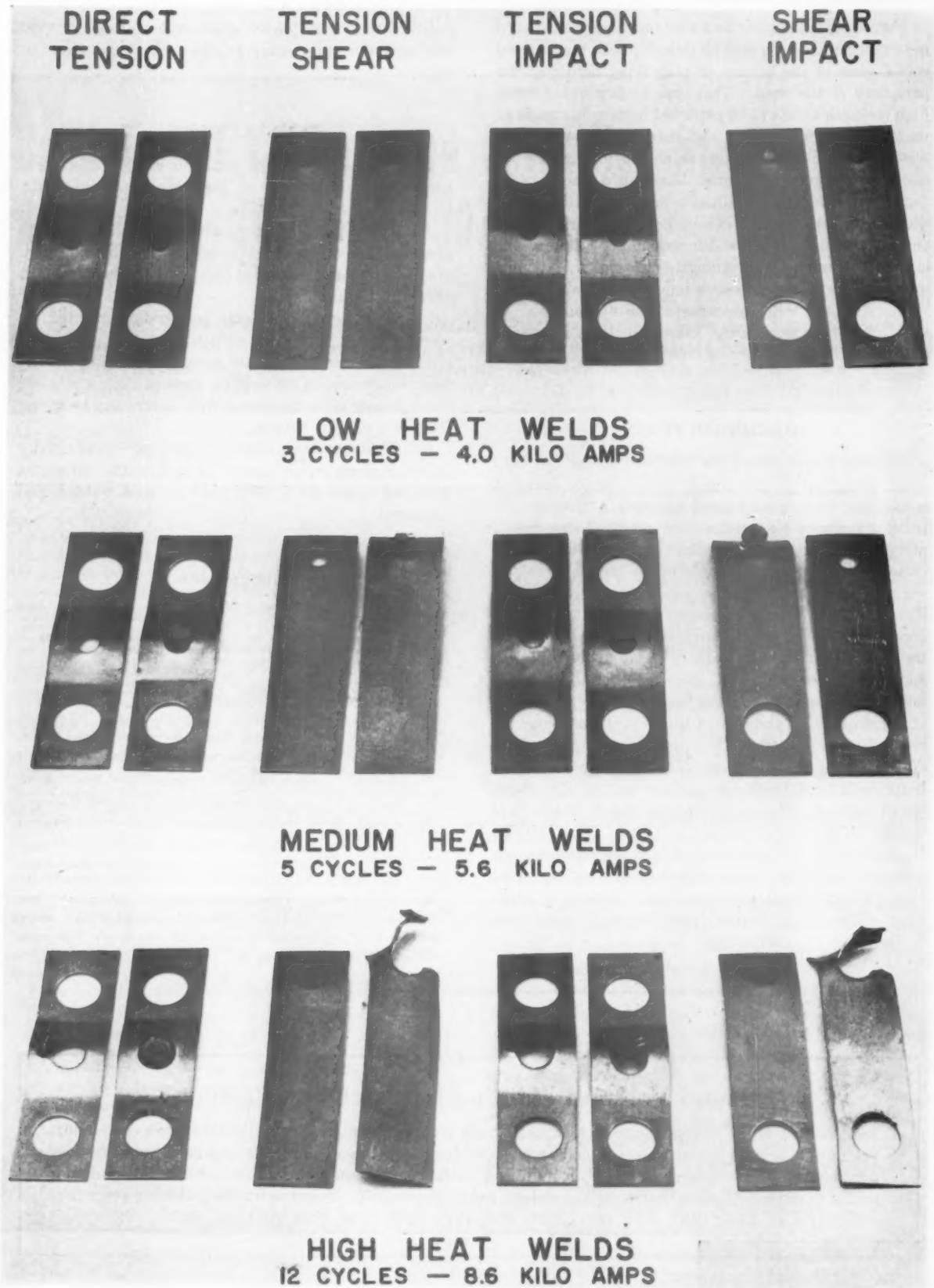

Fig. 10 Typical failures obtained in spot-welded Ti75a

In Fig. 10 (*b*) the current and weld time was increased to near optimum setting and all failures, both tension and shear, were of the button or plug type, failing at the periphery of the weld. This type of failure indicated high strength and is to be expected from welds made at optimum setting. When the current and weld time were increased still further, as shown in Fig. 10 (*c*), the weld nuggets were much larger in diameter. All failures under these conditions were primarily a tear around the weld, which can be partially attributed to the fact that the sheet width was small. Due to the size of the nugget the strength was higher, but this advantage is offset by greater indentation and penetration. Also the weld appearance was not as good as with lower current settings. Both the low heat welds and the medium heat welds indicate a weld of average ductility.

HARDNESS TESTS

In order to determine the hardness across the weld quite a number of specimens, welded under different conditions, were sectioned and mounted for testing. In a few specimens Knoop hardness readings were taken across the nugget at rather close intervals but in most cases readings were taken only in the parent metal, at the edge of the weld and the center of the weld nugget. Traverse tests across specimens welded at optimum conditions showed a fairly uniform hardness across the weld, the hardness being slightly higher at the center of the weld nugget. For 75A, 22-gage material, the hardness of the parent metal was approximately 195 KHN (1 Kg. load). At the edge of the weld the hardness increased to about 240 KHN with readings approaching 250 KHN near the center. This increase in nugget hardness is hardly sufficient to cause any concern about embrittlement. On the specimens tested which were welded with various current and weld time settings there was little evidence to show that the hardness was affected. Most specimens with high current and weld time settings actually showed a slight decrease in hardness. These tests verified previous tests made and indicate that there is no appreciable change in weld hardness due to changing either the weld time or current.

CONCLUSIONS

1. Commerically pure titanium can be effectively spot welded, resulting in high-strength welds with moderate ductility.
2. Under most conditions a ductility ratio or tension shear to direct tension ratio of 0.35 can be expected. Weld current and weld time apparently have only slight effect upon these values.
3. Weld hardness is only moderately affected by varying either current or weld time.
4. Impact strengths are increased directly as the heat is increased in the welding process.
5. Under most conditions weld failure will be in the form of a plug or button.
6. Weld strength characteristics of commercially pure titanium most nearly approach the strengths obtained when SAE 1035 steel is spot welded and tempered.

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Bound Volumes Welding Research Supplement

An inventory of the bound volumes indicates that the Welding Research Council could spare a few bound volumes for certain years. The Council proposes to dispose of these volumes as long as they last at $15 per volume. Each volume is bound in imitation leather covers and contains as index. Each volume probably represents more than a million dollars worth of research. Volumes for the following years are still available: 1939, 1940, 1941, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951 and 1952.

Behavior of Carbon and Low-Alloy Steels Between −20 and +650° F

PVRC-sponsored report demonstrates that certain pressure vessel steels may be susceptible to the phenomenon of brittleness in temperature ranges which, from the engineering viewpoint, are normally considered neither "high" nor "low." Appropriate precautions to be observed in critical applications are also discussed

by G. H. Enzian

Summary

The temperature limits −20 and +650° F bound on one hand the lowest temperature commonly accepted as encompassed in the term "atmospheric," and on the other hand the approximate highest temperature below which recognition is not commonly given to the possibility of creep flow in carbon and low-alloy steels.

Within this range of temperature, two phenomena of considerable practical importance are encountered, namely notch brittleness and strain aging. The former is commonly encountered at room or lower temperature and is characterized by a transition within relatively narrow temperature limits from relatively ductile to relatively brittle behavior. On the other hand, strain aging is commonly encouhtered only at room and higher temperature; in susceptible steels the tensile strength rises to a maximum at about 500° F, and there is a corresponding minimum in elongation and reduction of area. It is significant, however, that the yield strength decreases with increasing temperature irrespective of changes in other properties.

Although strain aging and low-temperature brittleness are similarly affected by certain metallurgical variables, there appears to be no relation between the two phenomena. Mechanistically, strain aging is attributable to precipitation, whereas low-temperature brittleness is generally considered to be an inherent characteristic of ferritic iron. The effects of specific variables are as follows:

Notch-transition temperature may be lowered by:

1. Increasing degree of deoxidation.
2. Normalizing, or quenching and tempering.
3. Decreasing grain size.
4. Increasing ratio of manganese to carbon contents.
5. Alloying with certain elements, e. g., nickel.
6. Removal of the effects of cold work or strain aging, if present.

Strain-aging susceptibility may be reduced by

1. Increasing degree of deoxidation, especially with strong nitride-forming elements.
2. Normalizing.
3. Alloying (comparatively little known, however).

The pressure vessel industry is concerned with the phenomenon of brittleness, induced either by low temperatures or by strain aging, in critical applications where such embrittlement may have a damaging effect on the serviceability of a vessel. This report demonstrates that certain steels may be susceptible to such effects in temperature ranges which, from the engineering viewpoint, are normally considered neither "high" nor "low." Where brittle behavior is considered a factor in service life, the appropriate precautions discussed in the report should be observed.*

INTRODUCTION

THE manner in which the properties and behavior of plain carbon and low-alloy steels vary with change in temperature between −20 and +650° F frequently has an important bearing on the performance of the material under fabricating conditions or in actual service. Between these limits, the tensile and impact properties change markedly, and seldom in a regular manner, with change in temperature. Indeed, it is generally impossible to use the properties determined at any one temperature to predict their probable value at another temperature without taking into account the complete history of the material (including method of manufacture, chemical composition, heat treatment, microstructure, etc.) and without an extensive background of experience with the behavior of similar material at various temperatures. Even then, it is often necessary to qualify the predictions because certain factors have not been completely explored and unexplainable exceptions are frequently encountered.

The steels to be considered in this report are those classified as carbon and low-alloy plate steels in the ASME Boiler Construction Code, Section VIII (1952), and in the API-ASME Code for Unfired Pressure Vessels (1951). Steels which qualify as low-alloy structural steels under ASTM Specification A242–49T are also included. These codes limit the carbon content of steels for welded construction to a maximum of

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This report has been prepared under the sponsorship of the Materials Division of the Pressure Vessel Research Committee of the Welding Research Council.

* Under certain circumstances, hydrogen embrittlement may also affect the serviceability of a fabricated vessel. This phenomenon is being dealt with in a report currently in preparation.

0.35%. Other specifications are contained in the ASTM Book of Standards, 1952, Part 1—Ferrous Metals.

The temperature range under consideration in this report is important to the metallurgist, design engineer and fabricator because the lower limit is within the scope of atmospheric variation even in the temperate zone, and the upper limit is frequently encountered in steel structures either during fabrication or in actual service. Therefore, it is important to know not only what properties can be expected of commercial steels at various temperatures, but also what effect exposure to these temperatures may have on the room temperature properties. In other words, whether the changes in properties are temporary or permanent.

Generally speaking, the changes in properties noted on lowering the temperature from normal are temporary.* Even exposure to temperatures as low as −320° F has been shown[1, 2] to have no permanent deleterious effect on the properties of low-carbon steels at normal atmospheric temperature.

On the other hand, the properties of steel exposed to temperatures higher than normal and then cooled are frequently quite different than they were before heating. This is especially true of steel which has been strained or cold worked, as in bending, punching or shearing, before heating. These permanent changes in properties are usually ascribed to "strain aging," a phenomenon which is greatly accelerated by slightly elevated temperatures. This behavior of mild steels has recently been quite thoroughly reviewed by Thielsch.[3] Although the present report is concerned with the properties of carbon and low-alloy pressure vessel steels *at* various temperatures up to 650° F, it is considered important to emphasize that these may be markedly different from the room temperature properties found *after* heating to elevated temperatures.

GENERAL CONSIDERATIONS

As a general rule, it can be said that the hardness and strength of a metallic material should vary inversely with the temperature, while the ductility varies directly.[4] However, it has long been known that ferrous metals do not always adhere to that rule, but, instead, exhibit a rather peculiar behavior in the so-called "blue-heat" range (about 400 to 600° F). According to Robin,[5] the fact that "iron possesses a maximum resistance to fracture at about 480° F" was established in 1850 by Fairbairn. Various investigators have confirmed the "blue-heat phenomenon," or the characteristic increase in strength and hardness and decrease in ductility in carbon steels, which Fettweis[6] associated with strain aging. Kenyon and Burns[7] used the increase in tensile strength at 400° F over the room temperature strength as a means of distinguishing between aging and nonaging material. Dean, Day and Gregg[8] demonstrated that the blue-heat phenomena were made more marked by increased nitrogen. On the other hand, Daniloff, Mehl and Herty[9] showed that aging effects can be minimized by drastic deoxidation and indicated that aging in steel was caused by "dissolved oxygen." Herty and Daniloff[10] also showed that the benefits of aluminum deoxidation "only become marked after normalizing, and not in the as-rolled condition." More recent work by Low and Gensamer[11] virtually eliminated oxygen as a cause of strain aging, and both Graham[12] and Enzian[13] showed that the tensile strength of low-carbon steels at 500° F could be directly related to the nitrogen content.

It is thus apparent that the change in the mechanical properties of steel between room temperature and 650° F is associated with strain aging, and is influenced to a considerable extent both by the nitrogen content and by the deoxidation practice used. In addition, there is some evidence that the behavior of steel in this temperature range also is affected by heat treatment.

Reasons for the changes in the properties and behavior of mild steel at temperatures below normal do not seem to be as well understood as those taking place at elevated temperatures and, until recently, have not been as well explored. In 1931, Russell[14] stated: "This is a region of less interest and slightly less importance than that of high temperatures. . . . Because only slight industrial use is made of materials at low temperatures and because failures in such cases are infrequent, there has been no great demand for knowledge of the properties of material in this condition of temperature."

The situation has changed considerably in the 22 yr that have elapsed since Russell's paper and knowledge of the properties of materials at low temperatures has become increasingly important. Indeed, a review of recent technical literature reveals far more papers dealing with the effect of low temperatures than with the "blue-heat" range.

In general, the tensile properties of steels change in a more or less regular and predictable manner with falling temperatures. Yield and tensile strengths (and hardness) increase gradually. The ductility, as measured by elongation or reduction of area, usually shows little change or only a slight decrease down to temperatures as low as −250° F.[15] However, the behavior of steels in the presence of a notch (and particularly in combination with shock loading as in Charpy testing) does not change in a regular manner with decreasing temperature. It is a characteristic of plain carbon and low-alloy (but not of austenitic stainless) steels to be embrittled at some temperature. The change from ductile to brittle behavior usually takes place abruptly within a relatively narrow temperature range, which, as McAdam and Clyne[17] point out, is characterized by inordinately high- and low-notch impact values with change from fibrous to granular fracture. The average temperature at which such embrittlement occurs has been termed the "transition temperature." Actually,

* An exception is found in subzero treatment of tool steels and in the mechanical working of certain austenitic steels at subzero temperatures.

however, the exact "average" temperature is frequently quite difficult to determine accurately and, furthermore, is dependent on the test method used to evaluate it. This subject has recently been reviewed in some detail by Armstrong, Kahn and Thielsch.[16]

The present report is not concerned with transition temperatures as such, but it is felt that an appreciation of this concept is essential to an understanding of the changes in the behavior of steels above and below room temperature. Although there is a tendency toward embrittlement in both directions, there is some question whether there is any relationship between "notch brittleness" (transition temperature) and the "blue-brittleness" associated with strain aging. At least one authority[17] in this field has stated that the mechanism of the transition temperature in metals is entirely unrelated to aging and the yield point phenomenon. On the other hand, it is known that, of the ferritic steels, those thoroughly killed and containing aluminum have the lowest transition temperatures[15] and display the least tendency toward strain-age embrittlement. Seigle and Brick,[18] after an exhaustive survey of the literature, concluded: "The metallurgical variables influencing changes in the mechanical properties of steel at low temperatures have not yet been satisfactorily analyzed in most cases." Although there may be some technical question of whether there is a relationship between the changes in properties above and below room temperature, there is at least circumstantial evidence to indicate that some of the important factors which minimize "blue-heat" phenomena also improve the toughness at low temperature.

CHANGES IN TENSILE PROPERTIES

The general effects of temperature on the hardness and strength of steel have been recognized for many years. In 1905, Hadfield[1] reported a comprehensive study of the properties of steel at liquid air temperature (about −300° F) and called attention to earlier work by Andrews, in 1886, on the strength of railway axles at −45° C (−49° F). In 1910, Robin[5] reported the results of crushing and hardness tests on steels of varying carbon content at temperatures from that of liquid air to about 1100° C (2010° F). As has previously been mentioned, Robin also cited work by Fairbairn in 1850 which referred to the increased strength of iron at "blue-heat" temperatures.

It seems safe to say, therefore, that the effect of temperature on the properties of ferrous materials has been of interest to many investigators for the past 100 years. Until recently, however, principal interest has been shown in the effect of elevated temperatures, and more attention has been paid to hardness and tensile strength than to yield strength. The absence of reliable information on the effect of temperature on the yield strength of mild steels recently prompted the Jernkontorets Technical Council to sponsor an extensive investigation of the effect of temperature on the tensile properties of all standard, unalloyed, Swedish pressure vessel steels.[19] The temperature range studied was from −40 to +750° F. The principal objective was to obtain data which would permit calculation of the strength of vessels at service temperature on the basis of yield strength rather than ultimate tensile strength values.

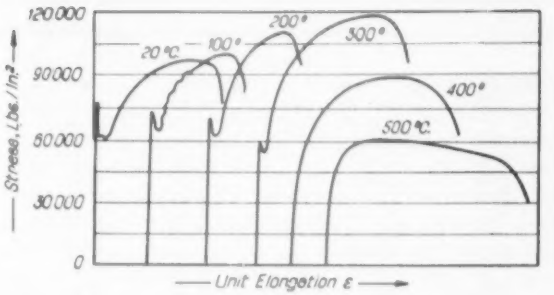

Fig. 1 Effect of testing temperature on stress-strain curves of steel. Note high ultimate strength value at 300° C, and the absence of a yield point at higher temperatures (from Kenyon and Burns[20])

Yield Strength

The characteristic yield point (drop of beam) of soft, mild steels disappears at elevated temperature. This is a gradual change, with increasing temperature, as seen in Fig. 1, and it is difficult to determine the exact temperature at which it disappears. However, several investigators have noted that a definite yield point is not observed at temperatures above about 300° C (570° F). This change in behavior increases the difficulty of studying the effect of temperature on yield strength—particularly without the advantages of modern autographic extensometers—and, perhaps, partially explains why so little information on this question can be found in the early literature.

The tests reported by Lilljekvist[19] with all standard unalloyed Swedish pressure vessel steels showed a progressive decrease in yield strength with increasing temperature for all the steels investigated, regardless of whether they were rimmed, silicon-killed or silicon-aluminum-killed. The compositions of the 11 basic open-hearth heats representing four standard grades are shown in Table 1. It was also reported that the shape of the curves was not affected by prior heat treatment. The results are summarized in Fig. 2, which shows the minimum yield strength values to be expected at various temperatures for standard steels with the indicated room temperature yield points. (The shift in the curves at 570° F (300° C) is the result of a change in the method of expressing the yield strength; the lower yield point value was used up to this temperature, and the stress for 0.2% permanent set was used at higher temperatures.)

These results are not in disagreement with others who have reported the effect of temperature on elastic properties. Schwinning, Knoch and Uhlemann,[21] showed

Table 1—Chemical Compositions of Standard Swedish Pressure Vessel Steels[19]

SIS Grade	*Heat No.*	*C*	*Mn*	*P*	*S*	*Si*	*Total Al*	*Practice*
1330	9993 FJ (rim)	0.15	0.31	0.014	0.023	..	0.004	Rimmed
	9993 FJ (core)	0.25	0.34	0.023	0.051	..	0.004	Rimmed
1330	X3640	0.10	0.40	0.040	0.038	0.28	0.013	Si-Al-killed
1330	X2972	0.08	0.33	0.012	0.035	0.18	...	Si-killed
1330	X2611-1	0.08	0.39	0.026	0.033	0.29	0.019	Si-Al-killed
1330	X2611-2	0.07	0.39	0.024	0.035	0.27	0.001	Si-killed
1430	X2645-1	0.16	0.44	0.033	0.032	0.29	0.024	Si-Al-killed
	X2645-2	0.16	0.45	0.032	0.034	0.29	0.001	Si-killed
2112	X2646-1	0.16	1.15	0.037	0.030	0.32	0.025	Si-Al-killed
	X2646-2	0.17	1.13	0.037	0.032	0.31	0.001	Si-killed
M	E7333	0.16	0.49	0.024	0.017	0.29	0.002	Si-killed
	E7353	0.16	0.42	0.020	0.018	0.18	0.006	Si-Al-killed

no change in yield strength of a 0.12% carbon steel between room temperature and 400° F, even though the tensile strength increased approximately 16,000 psi over this range. Kanter and Spring[22] also found no increase in yield strength at blue heat temperatures in cast carbon and low-alloy steels.

Miller and Heger[23] recently prepared an excellent graphical presentation of published information on the elevated temperature strength of wrought plain carbon and alloy steels containing molybdenum and up to 3% chromium. No editorial comment was made on the change in yield strength with temperature, but their data showed that the only steel in which the yield strength did not decrease continuously with increase in temperature was a 0.5% Cr – 0.5% Mo steel. The curve for this material showed a slight indication of a small hump at 700° F which was, nevertheless, some 8000 psi below the room temperature value. However, in view of the fact that all other steels, regardless of alloy content, failed to show a similar discontinuity in the yield strength vs. temperature curve in the blue heat region, it seems doubtful that the 0.5% Cr – 0.5% Mo material is unique in this respect.

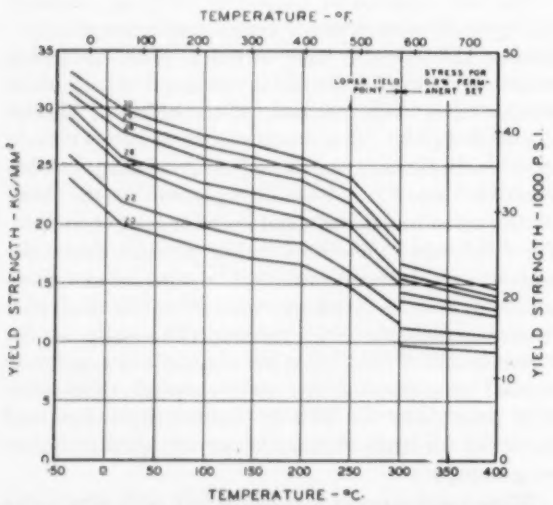

Fig. 2 Effect of temperature on yield strength of boiler plate steels. The numbers on the curves refer to the room temperature yield point in kg/mm² (Lilljekvist[19])

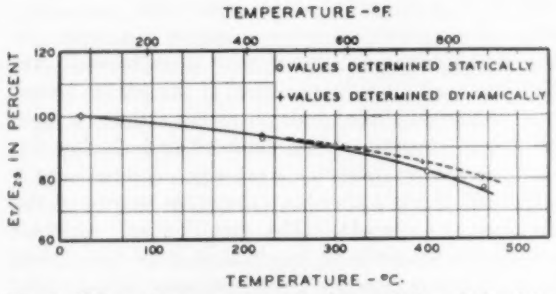

Fig. 3 Effect of temperature on the modulus of elasticity (E_t) of carbon steel. Room temperature value (E_{25} = 100%) = approximately 30,000,000 psi (Versé[25])

Work by Tapsell,[24] Versé[25] and others has shown that the modulus of elasticity (Young's Modulus) of carbon and low-alloy steels decreases continually with increase in temperature. Figure 3 shows the decrease in this property is practically linear from room temperature to about 600° F.

These results indicate that the elastic properties of plain carbon and low-alloy steels can be expected to decrease gradually with increase in temperature between −20 and +650° F. The general level of the yield strength over this temperature range will be affected to some extent by chemical composition and steelmaking practice, but these factors apparently have little effect on the rate at which this property changes with temperature.

Tensile Strength

As previously mentioned, the hardness and strength of ferrous metals tend to increase as the temperature is either raised or lowered from normal. The change with decreasing temperature is continuous, presumably to absolute zero.* On the other hand, the change with increasing temperature does not follow a regular pattern. The shape of the curve, and the temperature for maximum strength, is influenced by many factors in-

* There seems to be some question as to whether the mechanical properties of metals and alloys have been tested "at sufficiently low temperatures to contemplate their approach to absolute zero" (see Kanter, discussion to paper by Seigle and Brick[16]), but there are numerous references showing steadily increasing strength with decreasing temperature at least to within 20° C (36° F) of absolute zero.[14, 15]

cluding chemical composition, steelmaking practice and heat treatment.

Sauveur and Lee[26] made hardness and tensile tests at various temperatures on electrolytic iron and a series of steels with varying carbon content. They observed that the temperature for maximum hardness and strength varied from 480° F for electrolytic iron to 750° F for steel with 0.75% carbon. Inokuty[27] noted that the peak in the tensile strength versus temperature curve for Armco iron and annealed steels containing up to 1.3% carbon occurred within a fairly narrow range between about 450 and 550° F. His data, shown in Fig. 4, indicate also that the increased strength imparted by increased carbon content is retained to some degree at all temperatures even up to 1300° F.

Similar disagreements in the data of various earlier investigators concerning the effect of chemical composition (principally carbon) on the temperature for peak hardness and strength can be cited, but all agree that anomalous behavior is to be expected in the blue-heat temperature range. In the light of present knowledge, it seems likely that insufficient attention was given to "minor" variations in the different steels tested. It is highly probable that steels which were considered, 30 or 40 yr ago, to be "identical" except for carbon content actually may have been far from it. Nevertheless, such discrepancies served a useful purpose by indicating that factors other than carbon content can impart individual characteristics to different steels and disturb any generalized trend of curves showing properties as a function of temperature.

Fettweis,[6] Galibourg[28] and others attributed the peak in the tensile-strength curve at blue-heat temperatures to strain aging taking place during deformation. Sauveur and Lee[26] concluded that this phenomenon was a property of the ferrite and not of the carbon-bearing constituent of the steel. Körber and Dreyer[29] also investigated this matter and showed that ingot iron strained at blue heat was stronger and less ductile than the same material cold worked at room temperature and aged at the elevated temperature. Sauveur[30] studied the effect of deformation at slightly elevated temperatures on the room temperature hardness of electrolytic iron and of steels of varying carbon content and, as shown in Fig. 5, found that deformation in the blue-heat range results in higher hardness than the same degree of deformation at room temperature. Tapsell[24] verified this behavior and also showed that the difference in hardness increased as the amount of deformation increased.

Sauveur[30] and van Wert[31] showed that there was a fundamental difference in the mechanism of deformation at blue heat and at room temperature. Dean, Day and Gregg,[8] Kühle[32] and others explained this

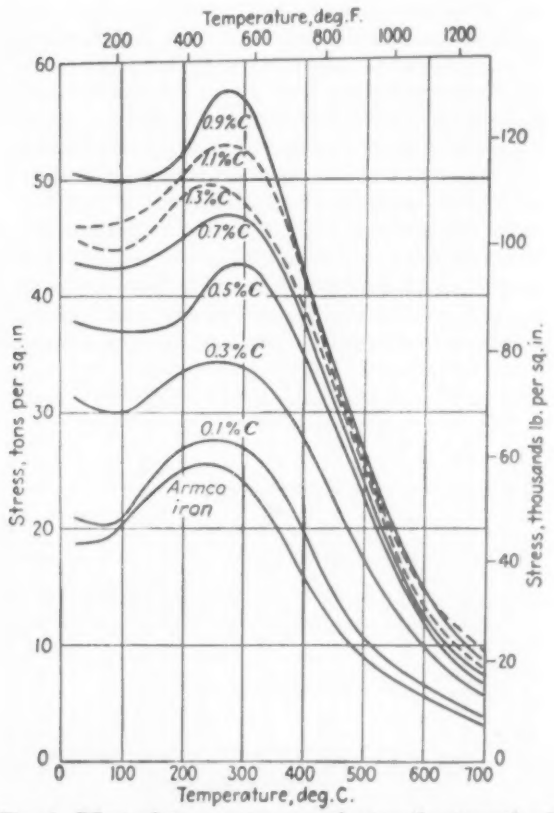

Fig. 4 Effect of temperature on the tensile strength of Armco iron and annealed carbon steels (Inokuty,[27] Sisco[4])

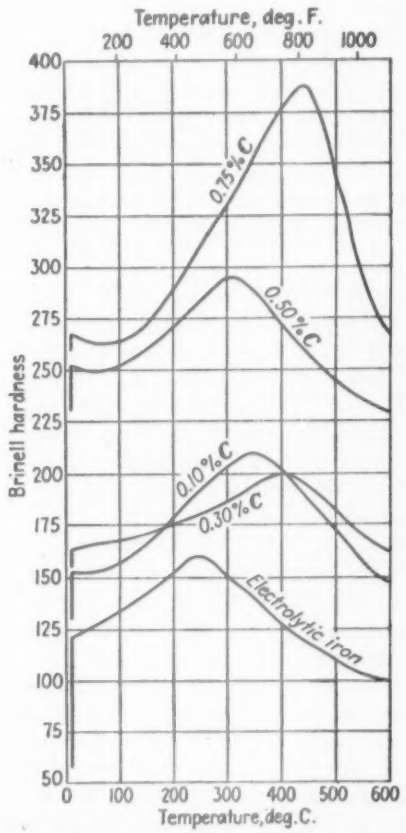

Fig. 5 Brinell hardness at room temperature after straining at the indicated temperatures (Sauveur[30])

difference on the basis of a precipitation-hardening phenomenon occurring during deformation at the elevated temperature. The precipitation-hardening theory as the cause of strain aging and blue-heat phenomena has now gained wide acceptance but, as Thielsch[3] recently pointed out, "there are many gaps in our technical knowledge of strain-aging embrittlement." Despite such gaps, considerable progress has been made toward a better practical understanding of factors affecting the properties of steels within the temperature range in question.

In most cases, hardness and strength start to increase at temperatures only slightly above room temperature. In other cases, notably in the so-called "nonaging" or "stabilized" steels, these properties may continue to decrease up to 300 or 400° F before the trend is reversed. In such steels, the increase may or may not be sufficient to exceed the room temperature value and the curve may indicate only a slight deviation in the downward trend in the blue-heat range. Neuendorff[33] called attention to the absence of a peak in strength and hardness at blue heat in low-carbon Izett steel, which was an early aluminum-killed grade made in Germany.

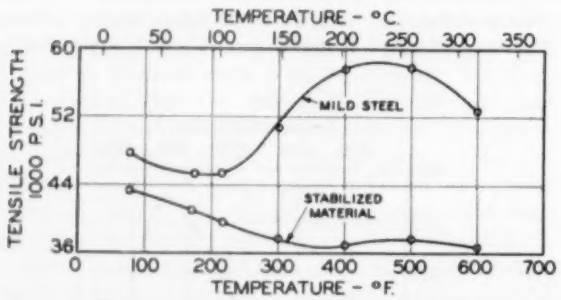

Fig. 6 Effect of testing temperature on the tensile strength of rimmed steel and stabilized steel (0.05% carbon) (from Hayes and Griffis[34])

Figure 6, from Hayes and Griffis,[34] shows the difference in tensile strengths, at elevated temperature, of an 0.05% carbon rimmed steel and a similar steel which was stabilized with aluminum and titanium during its manufacture. The mild steel showed a peak in tensile strength at about 450° F which was almost 11,000 psi higher than at room temperature whereas the tensile strength of the stabilized material was about 6000 psi lower at 500° F than at room temperature.

Kenyon and Burns[7] utilized this difference in tensile behavior at elevated temperature as a rapid index of the relative aging susceptibility; the increase in tensile strength at 400° F being taken as the measure of strain-aging capacity.

In tests on hot-rolled commercial Bessemer steels, Graham[12] showed that the tensile strength both at room temperature and at 500° F could be related directly to nitrogen content. Figure 7 shows that increasing nitrogen content had a greater effect on the tensile strength at 500° F than at room temperature.

Tests on normalized silicon-killed steels of varying nitrogen and phosphorus content by Enzian[13] showed

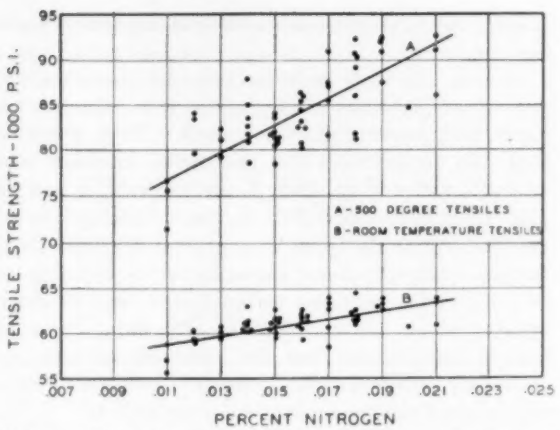

Fig. 7 Effect of nitrogen content on the tensile strength of Bessemer steels at room temperature and at 500° F (Graham[12])

that although both elements increased room-temperature tensile strength the additional strength of Bessemer steel at blue-heat temperatures, noted by Graham, could be accounted for entirely by the effect of nitrogen on strain aging. Figure 8 shows the relationship between nitrogen content and the increase in tensile strength at 500° F over the room temperature strength. It should be noted that variation in phosphorus content between 0.012 and 0.123% (which represents somewhat more than the normal difference between open-hearth and Bessemer steels) did not noticeably affect strain-aging susceptibility. From this it can be inferred that nitrogen tends to increase the elevated temperature tensile strength more than would be expected on the basis of room-temperature tests, but phosphorus does not. The effect of phosphorus on the elevated temperature strength of steel is apparently no greater than its effect on the strength at room temperature.

The tensile properties of various open-hearth and Bessemer steels at elevated temperatures were studied by Wright.[35] Figure 9 shows that the undeoxidized (capped) steels of both grades and those killed only with silicon were susceptible to increased strength in the blue-

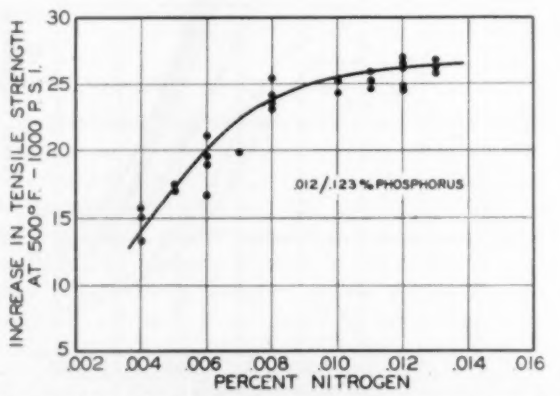

Fig. 8 Effect of nitrogen content on the increase in tensile strength of low-carbon steels at 500° F (Enzian[13])

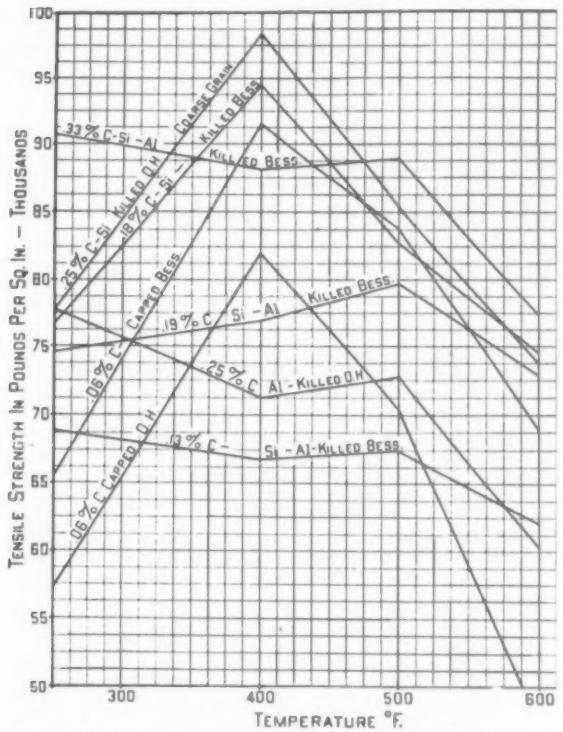
TENSILE STRENGTH IN POUNDS PER SQ. IN. — THOUSANDS
TEMPERATURE °F.
.33% C-Si-Al — COARSE GRAIN KILLED BESS
KILLED BESS
.25% C-Si — KILLED O.H.
.19% C-Si — KILLED BESS
.25% C CAPPED BESS
.19% C — Si — Al — KILLED BESS
.06% C
.25% C Al - KILLED O.H.
.13% C — Si - Al - KILLED BESS
.06% C CAPPED O.H.

Fig. 9 Tensile strength of open-hearth and Bessemer steels at blue-heat temperatures (Wright[38])

heat range, but the steels treated with aluminum—whether open-hearth or Bessemer—were not. The somewhat higher strength of the Bessemer steels as compared to corresponding open-hearth material at all temperatures can be accounted for on the basis of the differences in phosphorus contents.

Lilljekvist[19] found that the behavior of Swedish boiler plate steels at elevated temperature was influenced by the steelmaking practice (i. e., whether rimmed, silicon-killed or silicon-aluminum-killed). Figure 10, taken from this study, summarizes the effect of temperature on the tensile strength of two of the standard grades; note that the rim and core portions of the rimmed heat of SIS—1330 grade were tested separately.

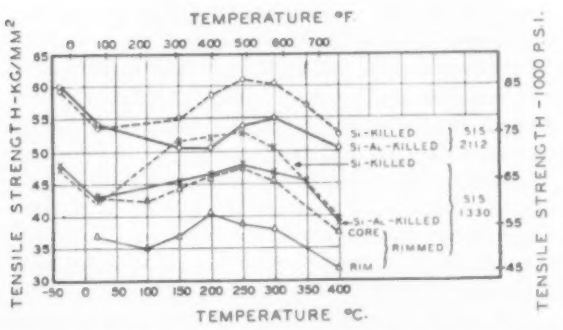

Fig. 10 Effect of temperature on the tensile strength of boiler plate steels. See Table 1 for chemical compositions (Lilljekvist[19])

All steels tested had higher tensile strengths at an elevated temperature than at room temperature but the increase was least for the steels killed with aluminum. It should also be noted that no effect of the aluminum deoxidation was found between −40° F and room temperature.

Wilder[36]-also compared the properties of killed and undeoxidized Bessemer and open-hearth steels and found that the nonaging characteristics of the aluminum-killed material were not obtained in the as-rolled condition, but only after normalizing at 1650° F. These results confirmed previous observations of Herty and Daniloff.[10] Graham and Case[37] attributed the effect of aluminum deoxidation to the formation of aluminum nitride. Work and Enzian,[38] using the analytical technique developed by Beeghly,[39] showed evidence of the presence of aluminum nitride in aluminum-killed steel. Comstock and Lewis[40] obtained nonaging characteristics by deoxidation with titanium, and Epstein[41, 42] developed a nonaging rimmed steel using vanadium.

In their review of published information on the strength of wrought carbon and alloy steels (up to 3% Cr − 1% Mo) at elevated temperatures, Miller and Heger[23] observed: "Most of the steels show only a slight decrease of strength from room temperature to 600 or 700° F. Indeed, in the carbon and molybdenum steels, the tensile strength actually increases with increase of temperature from room temperature to 400 or 600° F (the blue brittle range). It is noteworthy that this increase of strength is not so apparent in the chromium-bearing steels." No details concerning the deoxidation practice used or the condition of heat treatment of these materials were given, but it is possible that appreciable amounts of chromium in steel may have an effect on aging similar to that obtained with small amounts of aluminum.

It is clearly evident that the change in tensile strength of plain carbon and low-alloy steel between −20 and +650° F varies widely in different steels. The general level of strength over these temperature limits is influenced by chemical composition but the shape of the curve is most markedly affected by deoxidation practice and, in some cases, by heat treatment. The characteristic increase in tensile strength at blue-heat temperature is the result of strain aging which can be directly attributed to nitrogen and which can be controlled, within limits, by deoxidation with a strong nitride-forming element such as aluminum, titanium or vanadium.

Static Ductility

In general, the static ductility of steels, as measured by tensile elongation and reduction of area, varies with temperature inversely to the strength and hardness. This characteristic behavior is responsible for the term "blue brittleness" in the early literature although, as will be shown later, the reduced static ductility as-

sociated with the increased hardness and tensile strength at slightly elevated temperatures is not accompanied by a corresponding loss of impact toughness. It will also be shown that neither is high ductility in tensile tests at low temperatures necessarily indicative of adequate notched-bar toughness.

The change in tensile ductility between room temperature and −20° F is so minor that little discussion of it is needed. Many investigators have shown only a slight decrease in elongation or reduction of area values in ferrous materials even at very low temperatures. A recent review[18] stated: "The ductility as measured by the tension test shows little change or decreases slightly down to temperatures near −250° F, below which there may be a sharp drop." The most susceptible of a series of steels studied by Gruschka[43] retained 85% of its room temperature value for reduction of area to −140° C (−220° F). The results reported by Lilljekvist[19] showed losses of the order of two or three percentage points in reduction values and virtually no change in elongation values between room temperature and −40° F for Swedish boiler plate steels.

The various investigators of blue-heat phenomena seem to attach somewhat less significance to the details of changes in static ductility than to tensile strength or hardness. In most cases it is merely observed that elongation and reduction of area values showed minima at approximately the temperature for peak hardness and strength.

Figure 11, from Kenyon and Burns,[20] shows the result of Reinhold's[44] investigations of the effect of temperature on tensile properties of mild steel. No comment is made of the fact that the minimum in the reduction of area curve practically coincides with the temperature for peak tensile strength whereas the low point in the elongation curve occurs almost 150° C lower, at about 125° C (260° F). Jeffries[45] also observed a similar difference in the temperatures for minimum elongation and reduction of area in annealed Armco iron, but in his material these occurred at about 350 and 600° F, respectively.

Mehl and Briggs,[31] in discussion of van Wert's paper, showed a comparison of the effect of temperature on

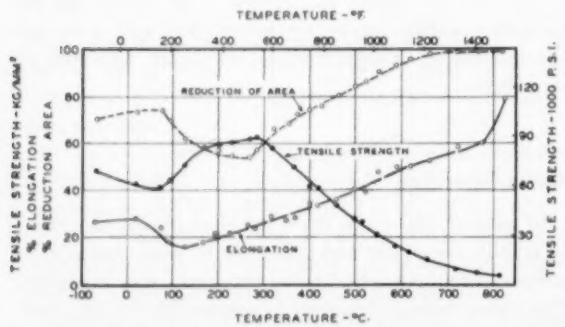

Fig. 11 Effect of temperature on tensile properties of mild steel (Reinhold,[44] Kenyon and Burns[20])

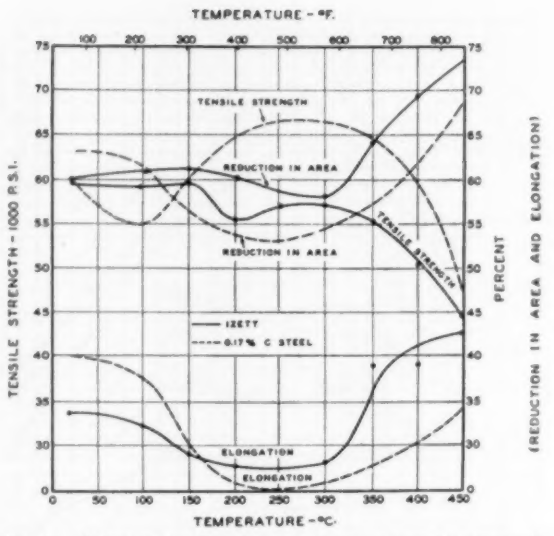

Fig. 12 Effect of testing temperature on tensile strength, elongation and reduction of area of mild steel and Izett (Mehl and Briggs[31])

the German Izett steel (aluminum-killed, "nonaging") and "a steel of approximately the same composition and condition." Their results (Fig. 12) show that although there was little or no effect from blue brittleness on the tensile strength of Izett, there was a pronounced decrease in elongation values at blue heat compared to room temperature, with very little change in the reduction of area. In other words, there seems to be a better correlation between the effects of temperature on tensile strength and reduction of area than between tensile strength and elongation.

Wright[35] showed that the changes in ductility values with increasing temperature are similar in aluminum-killed Bessemer and aluminum-killed open-hearth steels, but did not report the changes in the steels which were markedly susceptible to aging. Wilder's data[36] indicate a greater loss in elongation than in reduction of area values at 450° F even in steels which were considered nonaging on the basis of tensile strength. For example, the aluminum-killed Bessemer and open-hearth steels normalized at 1650° F did not increase in strength at 450° F, as compared to room temperature (thus were nonaging) and showed no change in reduction of area. However, the elongation values decreased 26 and 12%, respectively, for the Bessemer and open-hearth heats at this temperature.

Lilljekvist's data[19] showed that both reduction of area and elongation values varied with the tensile strength, having minimum values at the temperature of maximum strength in all steels tested.

It seems fairly well established that both the elongation and reduction of area can be expected to decrease somewhat as the temperature is increased above normal. Although these two values are generally regarded as being merely different measures of the same property (static ductility), and are frequently used interchangeably, there is some evidence that they do not always behave in similar manners with temperature and may,

in fact, be influenced by different factors. It has been observed that elongation values consistently show a characteristic minimum at slightly elevated temperatures even in the so-called nonaging steels which are not susceptible to increased strength or decreased reduction of area at blue heat. Furthermore, the minimum in the elongation curve has also been noted to occur at a lower temperature than the inflection points for either the reduction of area or tensile strength curves. The significance of this behavior has not been explained or assessed.

CHANGES IN IMPACT PROPERTIES

The changes in impact properties of carbon and low-alloy steels over the temperature range under consideration are somewhat more spectacular and, in some respects, of greater importance than the changes in tensile properties or hardness. The latter properties have been shown to change gradually with change in temperature and over a rather broad range. In addition, the region near room temperature was seen to be the least critical for tensile testing; variations in the behavior of different steels were found principally in the blue-heat zone between about 400 and 600° F. Quite the opposite is the case with impact properties.

The lower end of the temperature range under consideration is most critical for dynamic testing of carbon and low-alloy steels. The transition from tough to brittle behavior at low temperatures is characterized by abrupt changes and considerable scatter in results; variation of only a few degrees in temperature frequently can result in a complete reversal of behavior. Above room temperature, variations in the behavior of different steels are, with few exceptions, generally minor. The general trend of changes in impact properties with temperature was shown by Epstein[46] in Fig. 13. It will be seen that all of the steels were characterized by sharp decreases in impact toughness with decreasing temperatures below normal—the temperature for this transition varied in different steels, but all reached a very low level at −80° C (−110° F). All steels tended to decrease in toughness at higher temperatures also, reaching a minimum at about 500° C (930° F) which, incidentally, is somewhat higher than the temperature for maximum tensile strength. However, it will be noted that although the general level of the curves at the higher temperatures varied in the different steels, in no case did it drop to the low level attained at subnormal temperatures.

It should be mentioned at this point that the room-temperature impact properties obtained after straining in the blue-heat range, or after heating cold-worked material to these temperatures, may be equally as low as those observed at subnormal temperatures, depending somewhat on the amount of cold working and the "strain sensitivity" of the steel.[3, 38, 54]

The changes in impact properties at elevated and at low temperatures will be discussed separately.

Changes in Toughness at Elevated Temperatures

Several investigators have studied the effects of elevated testing temperature on the impact toughness of steel, and have observed that the temperature for minimum impact toughness occurs at a considerably higher temperature than that at which a maximum loss of ductility is noted in a static tensile test. McAdam and Clyne,[47] and others, have explained this behavior on the basis of equalization between the rate of age hardening and the rate of deformation. For a comparatively slow type of deformation, as in tensile testing, the rate of aging equals the rate of deformation in the blue-heat range; in dynamic testing, the rate of deformation is apparently so high that the full effects of aging are not obtained until somewhat higher temperatures, and hence more rapid aging rates, are reached.

Greaves and Jones[48] observed that cold work altered

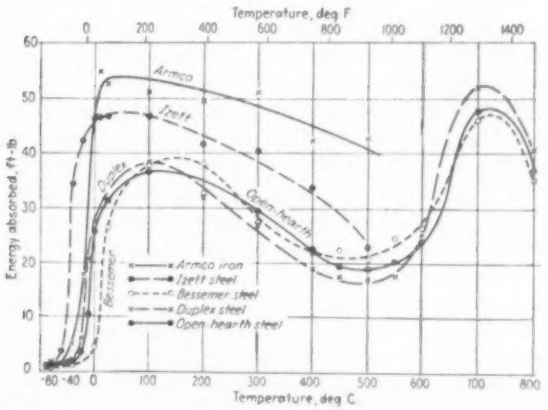

Fig. 13 Influence of steelmaking practice on the change in Charpy (keyhole-notch) impact toughness at various temperatures (Epstein[46])

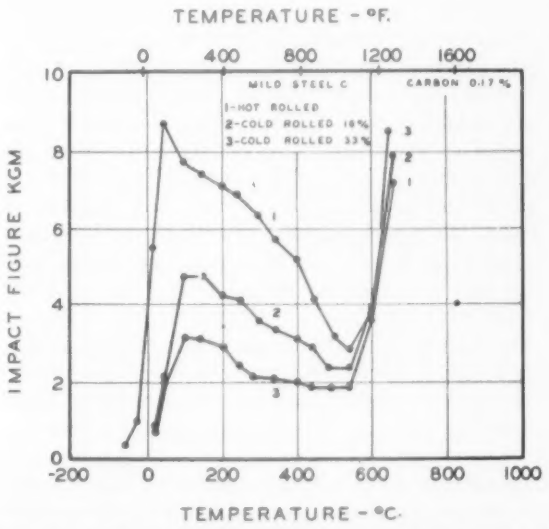

Fig. 14 Influence of cold work on impact toughness of mild steel at various temperatures (Greaves and Jones[48])

the effect of temperature on the impact toughness of steel. As shown in Fig. 14, increased amounts of cold work displaced the steeply sloping portion of the curve at the lower temperature end to a higher temperature (i. e., raised the transition temperature), and lowered the general level of the curve at all temperatures up to about 600° C (1110° F).

In recent years, comparatively little attention has been given to variations in impact properties at elevated temperatures, and the elevated temperature "brittleness" has not been studied in the light of modern concepts of brittle behavior. Although there is little question that at least part of the decrease in toughness observed at temperatures in the vicinity of 600° F can be explained on the basis of strain aging, it was seen in Epstein's data (Fig. 13) that the Izett steel, which is considered a nonaging material, also decreased in toughness at temperatures above 200° F. Gillett and McGuire[49] presented data on the impact toughness of ferritic steels at temperatures up to +375° F and observed that "even where the curve shows lower energy absorbed at +375° F than at room temperature, the fractures are of the tearing, rather than the brittle, type." Unfortunately, their data did not extend to blue-heat temperatures. The ASM Metals Handbook[50] summarized this question: "It is not known whether nonaging steel shows a less pronounced minimum than aging steel in the curve of impact resistance vs. temperature above the blue-heat region."

Changes in Toughness at Subnormal Temperatures

In recent years, it has become the practice to discuss changes in impact properties of ferrous materials at low temperatures in terms of "transition temperature"[16] rather than to present data showing specific impact values at various temperatures. There is good reason for this. For one thing, it is a proved fact that all ferritic steels become embrittled at some temperature. As Teed[51] recently pointed out: "If the results given in all the papers to which reference is made (on the change in notched-bar impact value of carbon steels with decrease in temperature) were to be expressed graphically, it would be found that those relating to ferritic steels would produce a family of curves of the type shown in Fig. 15 (of present paper). Due to a number of factors. . .the transition region occurs at a different temperature with different steels, though with carbon ones in general it lies within the range of +25 to −60° C (+77 to −76° F)."

The concept and the evaluation of the transition from tough to brittle behavior in pressure vessel steels have been discussed in some detail in a recent publication of this series.[16] The present report is concerned principally with changes in impact toughness (by conventional test methods) at temperatures above −20° F or, to put it another way, with those factors which determine whether the transition region lies above or below this temperature.

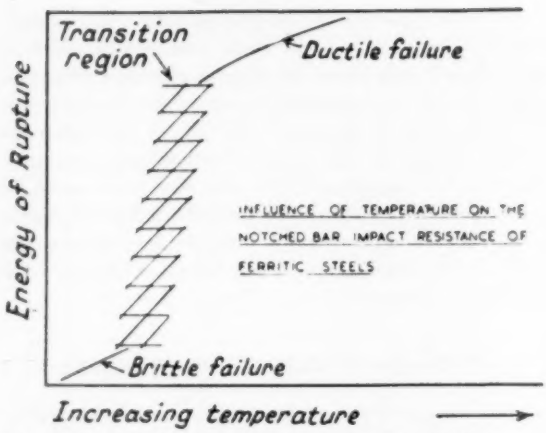

Fig. 15 Schematic representation of the influence of temperature on the notched-bar toughness of ferritic steels (Teed[51])

Epstein's work[46] showed that the steelmaking practice (i. e., whether open-hearth, Bessemer or duplex) used in the manufacture of carbon steels had a marked effect on the change in impact properties at subnormal temperatures (Fig. 13). Herty and McBride,[52] in 1934, clearly indicated the importance of deoxidation practice, heat treatment and grain size in the change of impact properties at low temperature. Although a great deal has been written on the subject in the intervening years, the work of Herty and McBride remains a much-quoted classic in studies of factors affecting the impact behavior of carbon in steels at low temperatures, and deserves particular mention.

The effect of deoxidation practice on the low-temperature impact properties of some of the steels studied by Herty and McBride is shown in Fig. 16 for the as-rolled condition and after normalizing at two different temperatures; the chemical compositions of the steels shown are listed in Table 2. With the exception that the silicon-aluminum-killed steel, SMA-17, contained 0.26% nickel, the steels can be considered similar in composition. It is clearly evident that, for equivalent conditions of heat treatment, best impact properties at all testing temperatures were obtained in the silicon-aluminum-killed material. In the as-rolled condition (1-in. rounds), however, impact toughness dropped to a rather low level at −20° F in all except the heat containing a small amount of nickel. Normalizing at 875° C (1605° F), which refined the grain size of all except the rimmed steel, greatly improved the impact properties of all steels except the rimmed heat. It is interesting to note that, in this condition, the semikilled steel (K-7) was better than the best steel as-rolled. Normalizing at 1100° C (2010° F) resulted in a very coarse grain size in all steels, but both of the silicon-aluminum-killed steels had better properties in this condition than they had as-rolled. Again, an apparently beneficial effect of the small amount of nickel inheat SMA-17 was noted.

Table 2—Composition of Steels Tested by Herty and McBride[52]

Heat No.	C	Mn	P	S	Si	Metallic Al	Ni	Practice
SMA-17	0.17	0.56	0.026	0.028	0.150	0.038	0.26	Si-Al-killed
SMA-15	0.15	0.71	0.010	0.029	0.074	0.025	...	Si-Al-killed
K-7	0.15	0.56	0.024	0.040	0.074	0.010	...	Semikilled
R	0.14	0.51	0.021	0.035	...	...	...	Rimmed

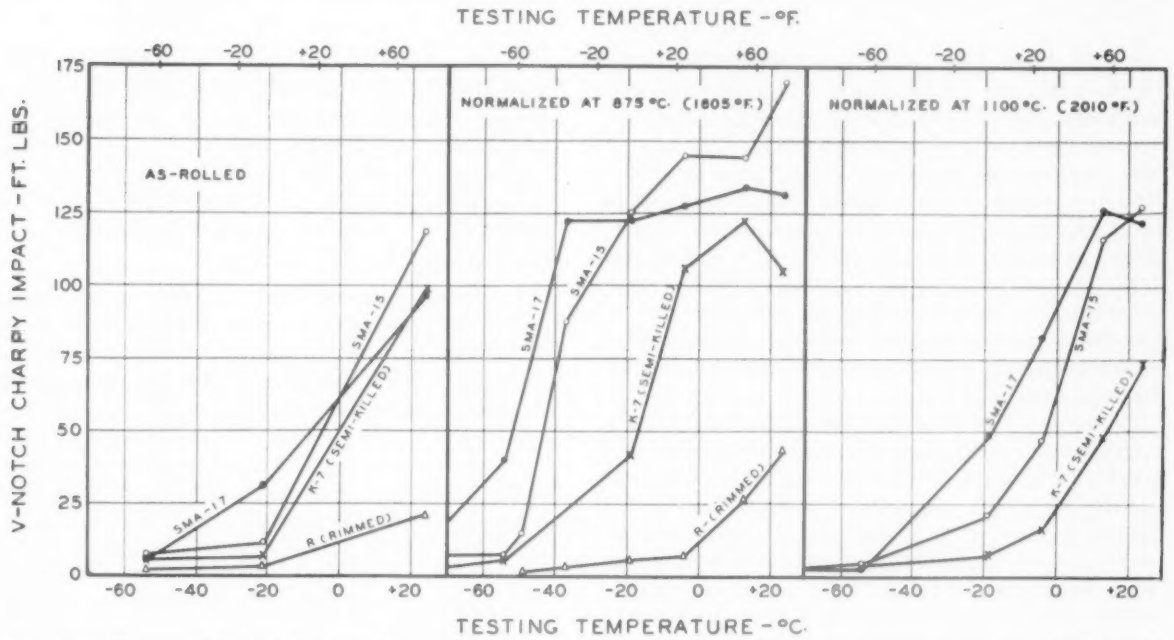

Fig. 16 Influence of deoxidation practice and heat treatment on the low-temperature impact properties of mild steels. (See Table 2 for chemical compositions.) (From Herty and McBride[52])

Numerous investigators have verified these observations on the effect of grain size and/or deoxidation practice on the low-temperature impact properties of carbon and low-alloy steels. Although there is still some question of the actual mechanism by which deoxidation practice affects the low-temperature impact behavior (e. g., whether because of a reaction with oxygen or nitrogen, or both), just as there is in the case of strain aging, there is abundant evidence that, for a given grade, best properties are obtained in material treated with aluminum, and produced to have a fine grain size. As Sisco[4] has stated: "Resistance to aging goes hand in hand with good low temperature behavior."

Unfortunately, because of limited supply and increased cost of the aluminum-killed material, it is impractical to use it in all structural and pressure vessel applications. From a steelmaking standpoint, fully killed steels have certain disadvantages which place practical limitations on the production of such material and result in higher costs. Thus, for economic and other reasons, large tonnages of structural steels must be made by rimmed or semikilled practices which permit higher production rates and lower costs. It is, therefore, important to know what factors affect the brittle behavior of steels which are not aluminum killed.

Perhaps the most important recent contributions along these lines have come as a result of work by Barr, Honeyman, Tipper,[53] and others, showing the importance of the manganese/carbon ratio on the brittle behavior of mild steels. This is shown in Fig. 17, taken from the paper by Barr and Honeyman, for material

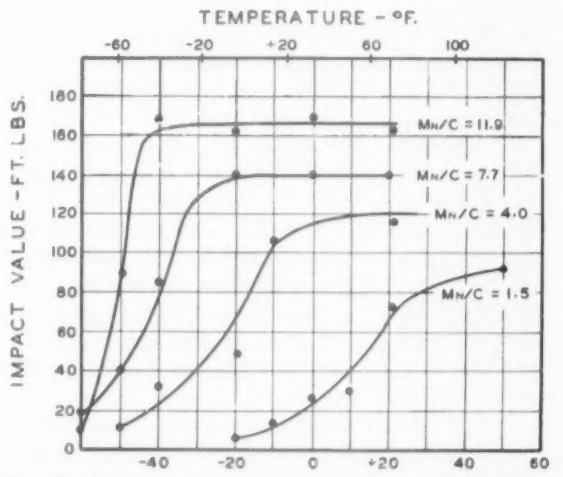

Fig. 17 Effect of manganese/carbon ratio on low-temperature impact toughness of mild steel. (See Table 3) (From Barr and Honeyman[53b])

Table 3—Composition of Steels Tested by Barr and Honeyman[55]

Heat No.	*C*	*Mn*	*P*	*S*	*Si*	*Mn/C ratio*
1229	0.19	0.27	0.012	0.034	0.12	1.5
1230	0.17	0.68	0.013	0.033	0.13	4.0
1278	0.115	0.89	0.015	0.029	0.13	7.7
1232	0.10	1.19	0.016	0.027	0.15	11.9

normalized from 1650° F. The chemical compositions of the steels are listed in Table 3. The carbon and manganese contents were varied to produce equivalent tensile strengths (approximately 63,000 psi) but in all other respects the steels were similar in composition. The change in impact toughness at −20° F with change in manganese/carbon ratio is remarkable: the steel with a ratio of 4.0 was as tough at −20° F as the 1.5 ratio material was at +50° F. On the basis of their investigations, Barr and Honeyman concluded: "A practicable recommendation would be that for shipbuilding steels the manganese/carbon ratio should not be less than 3.0."

In tests on hot-rolled, commercial, semikilled plate steels containing nitrogen varying between 0.005 and 0.011%, Enzian and Salvaggio[54] showed that the highest transition temperature found, using several criteria, in the steels with a manganese/carbon ratio of about 5.0 was as low or lower than the best of the steels having a manganese/carbon ratio of approximately 2.0. Comparisons of the best of the two grades showed that the higher manganese/carbon ratio lowered the transition temperature as much as 20 or 40° F, depending on the criterion used for its evaluation.

Although the above references point to the improved impact behavior of the steels with higher manganese/carbon ratios, there is reason for believing that much of the improvement can be ascribed to the lower carbon content required to obtain a given tensile strength. In commenting on the relative merits of the increased manganese and lower carbon contents, Sweeney[59] stated: "The beneficial effect of additional manganese is twofold. It not only decreases the transition temperature itself but, for the same strength level, it allows a decrease in carbon content."

There is limited information available indicating that as-rolled impact properties of some steels are influenced somewhat by rolling mill finishing temperatures. Sweeney[59] summarized recent published data on ship steels and observed that lower finishing temperatures favored slightly lower transition temperatures. He concluded, however, that: "the possible improvement resulting from a lowering of the finishing temperature may not be very great in the Class B and C (ABS) steels where it is desired."

In the field of low-alloy, high-tensile structural steels, the small amounts of nickel, chromium, molybdenum or copper which they contain are generally credited with having a beneficial effect on both strength and low-temperature toughness. Perhaps of equal importance is the fact that these steels are usually fully killed and have a fine grain size. The 1948 ASM Handbook[55] states: "Data obtained from studies of low-temperature toughness of these steels show that most low-alloy, high-strength structural steels are superior to the ordinary carbon steels. . . . This should be expected because these. . .steels are relatively low in carbon content and are thoroughly deoxidized."

It should be noted, however, that certain heat-treated low- and medium-alloy steels (notably those containing higher percentages of manganese and chromium) may exhibit unexpectedly poor impact toughness at room temperature and below. This type of embrittlement has been termed "temper brittleness" and is observed, in susceptible steels, after slow cooling from tempering temperatures above 1100° F, or after tempering in the range between 850 and 1100° F. This behavior is not fully understood, but "is undoubtedly a precipitation or aging effect, and as with other aging phenomena, appears to be less pronounced in strongly deoxidized steels."[55] Ordinarily, this type of embrittlement is not encountered in the steels under consideration here.

In summarizing their exhaustive survey of the mechanical properties of metals at low temperatures, Seigle and Brick[18] stated: "The metallurgical variables influencing changes in the mechanical properties of steel at low temperatures have not been satisfactorily analyzed in most cases. Grain size, aging characteristics, structural and compositional effects have not been studied with but a single controlled variable." Nevertheless, from a practical, rather than the technical standpoint, the large number of investigations made on the brittle behavior of commercial steels has provided a great deal of valuable information which now permits more intelligent selection of steels for specific applications.

In considering the application of mild steels for service at low temperatures, Keating and Mathias[2] concluded: "If precautions are taken to eliminate notches and the effects of cold work, fully killed mild steel of low-carbon content (under 0.15%) can safely be used at temperatures appreciably below 0° C (32° F)." The 1951 SAE Handbook[56] reduces the lower limit somewhat farther and states: "For most applications (to −25° F) it is probable that plain carbon steel will be satisfactory. In the lower part of this range where the service involves high stress concentration and high rates of strain, the selection of fully killed steels in place of rimmed or semikilled steels is justified."

CHANGES IN FATIGUE PROPERTIES

Comparatively little information is available on the effect of temperature on the fatigue properties of steel. Fatigue tests at temperatures other than normal are considerably more difficult to carry out than the short-time tensile or impact tests and, undoubtedly, the problems involved in maintaining close temperature control for long testing periods have discouraged more widespread investigation of this behavior.

In commenting on the effects of low temperatures on the fatigue behavior of ferrous materials in general, Russell[14] stated: "In every case the results at −40° F lie above those at room temperature. Thus, the endurance properties of polished specimens at low temperatures follow the increased tensile strength at these temperatures."

Teed[51] also concluded that fatigue strength increases with decrease in temperature down to −40° F, but observed: "This increase, however, is much less than that of the ultimate under comparable conditions." In further comment on fatigue tests on notched specimens, Teed stated: "With such a restricted number of results, the only safe conclusion is that, with these ferritic steels, the notch endurance limit is not worse but somewhat better at low temperatures than at normal ones."

It would appear from the literature that there is little interest in changes in fatigue properties of carbon and low-alloy steels at blue-heat temperatures, and this behavior has been investigated to only a limited extent. The reason for this may be, as Sisco[4] pointed out, that: "high alternating stresses are not often imposed upon structures or machined parts operating at elevated temperatures." Another possibility is that the operating stress conditions are too complex for adequate study by the simple form of fatigue test.

In reviewing the literature up to 1937, Sisco found conflicting results and concluded: "The data cited from all these investigations are insufficient to decide definitely whether the endurance ratio (i. e., fatigue strength ÷ tensile strength) will be approximately constant at elevated temperatures. They do, however, indicate that low- and medium-carbon steels up to say 400° C (750° F) will have at least an equal, and, at some intermediate temperatures, a higher endurance limit than at room temperature. . . ."

A handbook on fatigue, prepared for the Bureau of Aeronautics,[57] states: "It will be recalled that the tensile strength of different steels may rise with an increase in temperature and then fall with further increase, or may fall continuously. Endurance, on polished bars at least, may be expected to follow somewhat the same course." Although these remarks do not specifically classify steels as "aging" or "nonaging," a distinction between the two types is inferred and it is implied that in either case the fatigue strength vs. temperature curve should parallel that of the tensile strength.

It may be questioned whether the fatigue strength of steels at elevated temperatures should show a more direct relation to the tensile strength than to the yield strength. Unfortunately, however, there are insufficient data available in the literature from which a clear-cut conclusion can be drawn. It would be interesting to know, for example, how the fatigue properties change with temperature in modern nonaging steels which have lower tensile strengths at elevated temperatures than at room temperature. In addition, it has been shown that steels which show appreciable tensile strength increases at blue-heat temperatures have progressively lower yield strengths with increasing temperature. It does not seem reasonable that the fatigue strength should exceed the yield strength, or elastic limit, at any given temperature, but it may be possible that the yield strength of the material being tested may actually increase due to repeated stressing at slightly elevated temperatures and, in this manner, preclude a relationship between fatigue strength and the yield strength determined in short-time tensile tests.

These and other questions that might be raised concerning the change in fatigue properties at elevated temperatures can only be answered by additional investigations. However, the apparent lack of concern about the elevated temperature fatigue properties of carbon and low-alloy steels can probably be construed as indicating that this behavior is of minor importance in the selection of steels for applications within the temperature range of −20 to +650° F.

FIELDS FOR FURTHER STUDY

An attempt has been made throughout this review of known changes of behavior in steels within the temperature range of −20 to +650° F to call attention to certain areas where specific information is missing. Although a large amount of work has been done on the effect of temperature on the properties of metals in the past 100 or more years, it is apparent that a great deal remains to be learned in both the technical and practical aspects of the problem.

It should, perhaps, be first noted that the evidence available in the literature suggests the rather broad conclusion that elastic properties (i. e., stiffness and yield strength) decrease in a more or less regular and predictable manner with increasing temperature whereas those properties dealing with plastic deformation (hardness, strength, ductility or toughness), do not. The curves of these latter properties vs. temperature, in commercial steels at least, are characterized by discontinuities and pronounced maxima and minima; the location of these peaks and valleys is markedly affected by such factors as chemical composition, steelmaking practice and heat treatment.

The behavior of steels at temperatures in the blue-heat region can be explained on the basis of strain aging caused by a precipitation phenomenon which interferes with plastic deformation resulting in an increase in hardness and strength and a decrease in toughness. This behavior can be controlled, within limits, by suit-

able deoxidation of the molten steel and heat treatment of the finished material.

A similar explanation has not been advanced to explain low-temperature brittleness, and the fundamental factors involved are not completely understood. The theory that it is "characteristic" for ferritic materials to become brittle at some temperature does not adequately account for the variations encountered in commercial steels or for the observed effects of composition, heat treatment, etc., on brittle behavior. Additional knowledge is needed to point the way to practical steps which might be taken to assure optimum properties in commercially produced material.

By way of example, the behavior of aluminum-killed steels within the temperature range under consideration is especially susceptible to change by heat treatment. It is known that the best combination of properties in such material is obtained after a normalizing heat treatment to refine the grain size. The desirable properties usually associated with aluminum deoxidation often are not obtained in the as-rolled condition although this is the condition in which large tonnages of pressure vessel and structural steels must be used. What, then, are the factors which influence the properties of aluminum-killed steels and what practical steps can be taken to improve the properties, or at least assure uniformity, of commercial hot-rolled material?

These and other questions that can be raised concerning the behavior of steels within the temperature range of -20 to $+650°$ F can only be answered by continued research and investigation. Such work is being done and definite progress is being made; new information will continue to appear in the technical literature. It is hoped that this review of the subject will serve as a useful background which will permit a better understanding of the problems involved and the significance of the results obtained.

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Effect of Nitrogen and Carbon Dioxide Atmospheres on Arc Welding

The effect of the surrounding atmosphere on the formation, precipitation and distribution of oxide and nitride constituents

by F. W. Sowa, W. C. Truckenmiller and L. E. Wagner

ABSTRACT

The effects of air, nitrogen and carbon dioxide atmospheres on the physical properties and macro- and microstructures of arc welds produced with bare and coated electrodes are studied. The roles of the absorbed gases in the weld metal are discussed, and conclusions, supported by the physical test data and micro- and macrophotographs, are drawn concerning the effect of the surrounding atmosphere on the formation, precipitation and distribution of oxide and nitride constituents. The test results suggest the possibility of better evaluation of the protective effectiveness of electrode coatings for conventional consumable electrode metallic arc welding.

INTRODUCTION

THE value of exclusion of air from the molten pool of metal in consumable electrode metallic arc welding has long been recognized. With the inception of the modern coated welding electrode, applications of fusion welding increased tremendously in popularity because of the greatly improved mechanical properties of the deposited metal. In addition to other advantages possible with coating materials, it became possible to increase the stability of the arc with certain ingredients in the coating.

At the present time, the protective coverings over the weld area are of two types: (1) gaseous, as in inert arc welding and in conventional metallic arc welding through addition of gas forming ingredients in the coatings, and (2) liquid, with sufficient slag-forming ingredients in the coating to form a protective blanket over the heat-affected areas.

The lower physical properties, particularly shock resistance and ductility, obtained with bare (or lime washed) electrodes are due to the solution and perhaps reprecipitation as compounds of the nitrogen and oxygen from the air.

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The principal purpose in this investigation was to further evaluate the roles of absorbed gases on the properties of weldments. Atmospheres chosen were nitrogen and carbon dioxide, the former because it is a principal ingredient in the normal atmosphere and also could be obtained essentially free from oxygen, and the latter because it provided an oxidizing atmosphere free of nitrogen. Electrode materials chosen were AWS classifications E4510 and E6015. The former was chosen since it is essentially a bare electrode, free from gas and slag forming ingredients in any appreciable amount, thus permitting free access of the applied gaseous atmosphere either air, nitrogen or carbon dioxide. The E6015 electrode was chosen since it is free of any hydrogen-bearing compounds and nearly free of gas-forming ingredients which might mask effects produced by the atmosphere.

It was a secondary purpose of the investigation to ascertain the effectiveness of electrode coatings in preventing the surrounding gaseous blanket (normally air) from being absorbed in the molten metal pool.

TEST PROCEDURE

The stock selected to be welded consisted of 5- x 5- x $^1/_4$-in. SAE 1015 steel plates, which were surface ground to a thickness of 0.236 in. to remove any possible effects of surface oxides. A 30-deg bevel was milled on each plate transverse to the direction of rolling. The plates were then tacked in pairs for 60-deg vee-butt welds using $^1/_8$- x 1-in. backing strips and $^1/_8$-in. root spacing. At least three such pair of plates were prepared for each welding condition.

Welding rod selected for the tests were of two types, AWS classification E4510 and E6015, in $^1/_8$-in. sizes.

A Lincoln 300-amp direct-current arc welder was used for all tests. Voltage setting was "Normal" and current setting 130 amp for all tests. Straight (electrode minus) polarity was used for the 4510 rod, and reverse (electrode positive) was used for the 6015 rod.

Welds made in air were fabricated in the usual manner, and no further comment on their preparation seems indicated. For welding performed in both nitro-

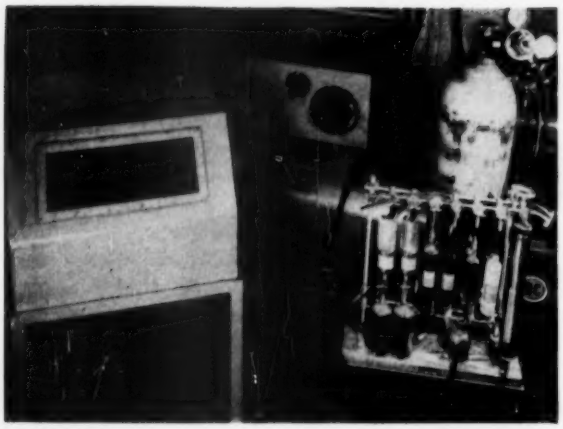

Fig. 1 Test apparatus used for welding in nitrogen and carbon dioxide atmospheres

gen and carbon dioxide atmospheres, the cabinet shown in Fig. 1 was used. After the pieces to be welded and the welding rod were placed in the cabinet, the gasketed access doors were sealed, and a plug seal was placed in the rubber gauntlet inside the leather welder's glove in the side of the cabinet. A small gas inlet and outlet were provided in the cabinet as well as a safety valve to take care of rapid gas expansion due to heating during welding. Flow of gas was started into the cabinet, and a positive pressure of approximately 4 in. of water was maintained during the purging period. The purging period was continued until in the case of the nitrogen atmosphere, the nitrogen partial pressure was at least 0.995, and in the case of the carbon dioxide atmosphere, the partial pressure of the carbon dioxide was at least 0.990. Gas analyses were made with the standard absorption type gas analysis apparatus shown in Fig. 1. When the partial pressure of the gas reached the value indicated above, the welding operator withdrew the gauntlet plug and quickly inserted his arm, the rubber gauntlet making a tight seal on the forearm. The slight positive pressure maintained during the purging period resulted in the escape of some gas at this time, but repeated tests of the gas failed to show any appreciable contamination by ingress of air. The welding operation was then performed in the cabinet, observable through the safety glass window in the front. Two or three pairs of plates were welded in each setup, minimizing as far as possible the number of times access to the cabinet was necessary. Limiting factors on the number of plates welded were operator discomfort and, in the case of E6015, electrode usage greatly reduced visibility in the cabinet due to smoke.

The plates were removed from the cabinet and the following for each atmosphere and each type of welding rod test specimens were made: two tensile specimens with $^1/_4$- x $^3/_4$- x 2-in. gage section; four $^1/_4$- x 1- x 10-in. guided-bend-test specimens, two root and two face; two adjacent transverse metallographic specimens approximately 1 $^1/_8$ in. long, one of which was annealed at 1625° F before metallographic polishing and examination. A 500-g Tukon hardness traverse at 0.010-in. intervals was made along the center of section on each of the as-welded metallographic samples. Photomicrographs were made at 100 and 500 diam of the unaffected base material and typical portions of the welds for each of the weld conditions. The annealed sections were examined metallographically. The as-welded sections

Table 1—Tensile Test Results

Rod spec.	*Atmosphere*	*Sample No.*	*Tensile strength*	*Elongation,%*	*Location and nature of failure*
4510	Air	1	52,900	7	Weld—Brittle
4510	Air	2	36,100	3	Weld—Brittle
6015	Air	1	51,300	10	Weld—Worm holes
6015	Air	2	58,700	15	Weld—Worm holes
4510	N_2	1	45,200	6	Weld—Poor fusion
4510	N_2	2	58,800	..	Outside gage length
6015	N_2	1	59,000	..	Outside gage length
6015	N_2	2	62,400	..	Outside gage length
4510	CO_2	1	No sample	..	.....
4510	CO_2	2	No sample	..	.....
6015	CO_2	1	62,000	..	Outside gage length
6015	CO_2	2	62,200	23	Weld—No visible defect

Table 2—Guided-Bend-Test Results

Rod spec.	*Atmosphere*	*Sample No.*	*Comment on face bend*	*Comment on root bend*
4510	Air	1	No failure	Brittle failure
4510	Air	2	No failure	Brittle failure
6015	Air	1	No failure	No failure
6015	Air	2	No failure	No failure
4510	N_2	1	Failed—Poor fusion	Failed—50% fusion
4510	N_2	2	Brittle failure	Failed—75% fusion
6015	N_2	1	No failure	No failure
6015	N_2	2	Failed—75% worm holes	Failed—50% worm holes
4510	CO_2	1	No sample	No sample
4510	CO_2	2	No sample	No sample
6015	CO_2	1	Weld defective—Bend OK	Weld defective—Bend OK
6015	CO_2	2	Weld defective—Bend OK	Weld defective—Bend OK

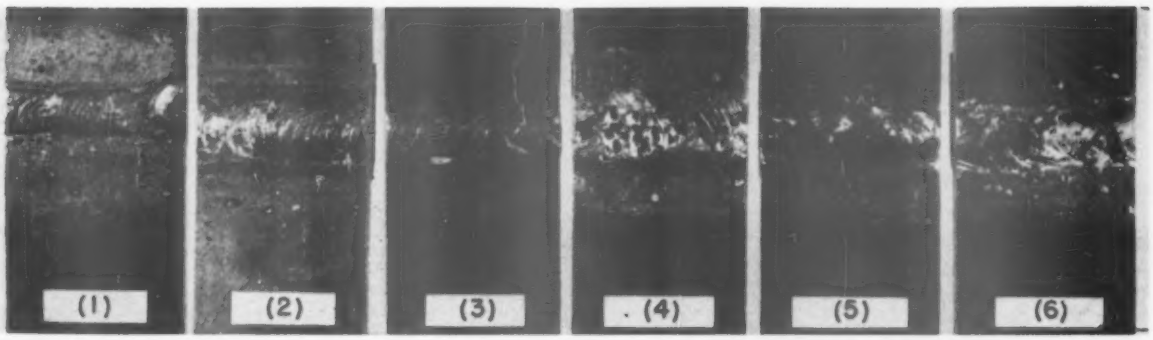

Fig. 2 Faces of typical samples of all six welding conditions: (1) E4510 rod in air, (2) E6015 rod in air, (3) E4510 rod in nitrogen, (4) E6015 rod in nitrogen, (5) E4510 rod in carbon dioxide, (6) E6015 rod in carbon dioxide

were further etched for macroexamination and photographed.

RESULTS

Results of the tensile tests are shown in Table 1, the face- and root-guided-bend tests in Table 2, and the Tukon hardness values of base material and welds in Table 3. Figure 2 is a photograph of the faces of typical portions of each type of test weld, Fig. 3, macrosections, and Figs. 4 and 5 photomicrographs, at 100 and 500 diam magnification, respectively, of welds produced under the same six test conditions. Table 4 is a summary of observations of the microstructures of the annealed welds.

DISCUSSION OF RESULTS

The results of tests obtained with E4510 welding rod appear to be representative. The weld bead, as seen in Figs. 2 and 3 is convex, fairly sound, and grain growth characteristics of the weld metal are normal. The

Table 3—Tukon Hardness Test Results

Material tested	*Number of tests*	*500 g Tukon hardness*
Untreated base material	60	157.6
Weld—4510 rod—air	33	176.6
Weld—6015 rod—Air	33	206.0
Weld—4510 rod—N_2	24	246.2
Weld—6015 rod—N_2	26	231.2
Weld—4510 rod—CO_2	33	169.9
Weld—6015 rod—CO_2	30	175.3

Table 4—Annealed Weld Structures

(All samples annealed at 1625°F.)

Rod spec.	*Atmosphere*	*Comments on microstructure*
4510	Air	Devoid of combined carbon, nitrides and oxides prevalent, nitride needles present
6015	Air	Normal structure, approximately 0.10% combined carbon, no nitrides
4510	N_2	Small amount of carbides (less than 0.10% carbon), no nitrides
6015	N_2	Normal structure, approximately 0.10% combined carbon, no nitrides
4510	CO_2	Devoid of combined carbon, oxides prevalent
6015	CO_2	Normal structure, no oxides, very little combined carbon

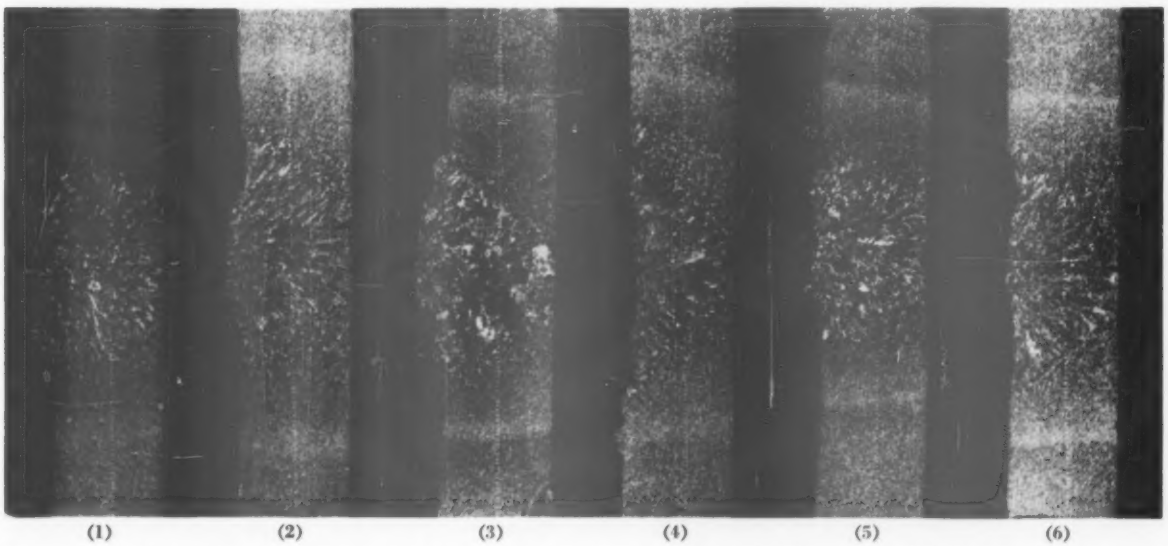

Fig. 3 Etched macrosections of all six welding conditions: (1) E4510 rod in air, (2) E6015 rod in air, (3) E4510 rod in nitrogen, (4) E6015 rod in nitrogen, (5) E4510 rod in carbon dioxide, (6) E6015 rod in carbon dioxide

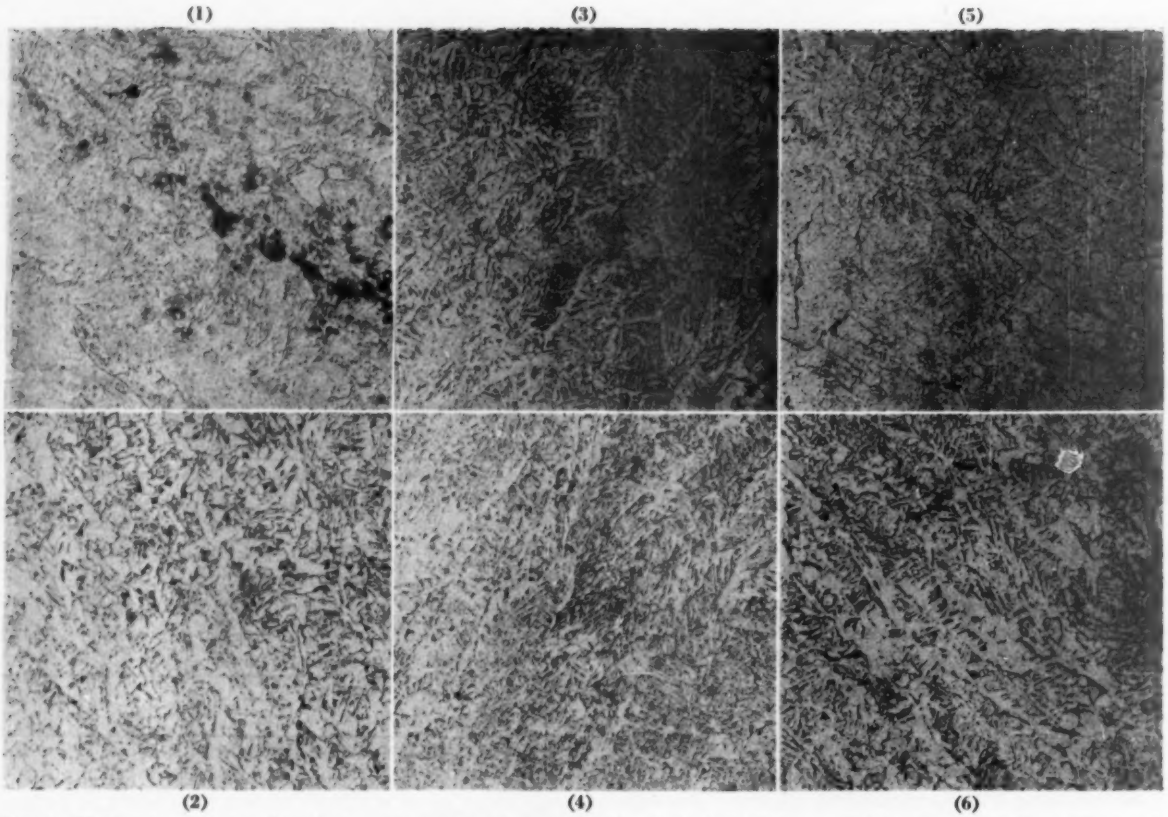

Fig. 4 Photomicrographs of typical portions of welds produced by six test conditions. Original mag. 100 diam. Nital etch

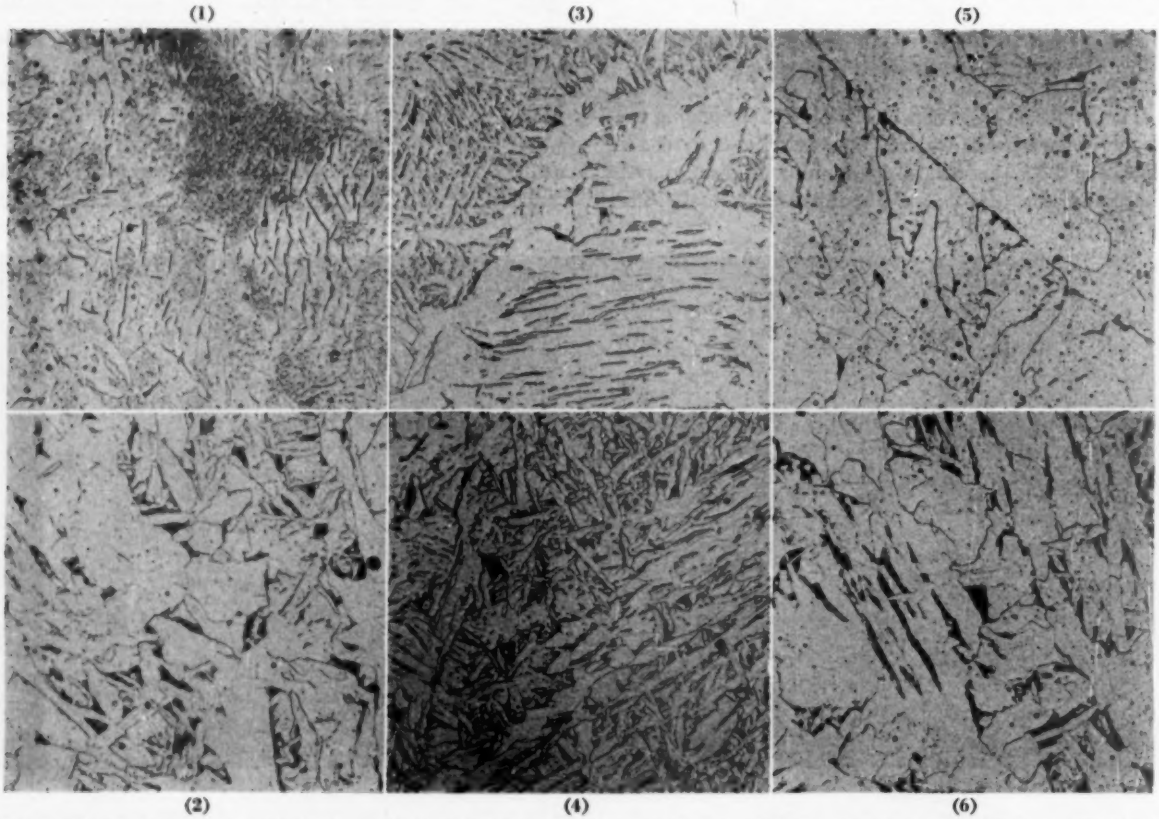

Fig. 5 Photomicrographs of typical portions of welds produced by six test conditions. Original mag. 500 diam. Nital etch

guided-bend tests indicate a considerable sensitivity on the root-bend specimens, failure being of a brittle nature and occurring at a slight angle of bend. Face-bend-test specimens were satisfactory. The difference between these two results could readily have been caused by slight imperfections in the fusion of the metal at the weld roots. Tensile test results show the expected low elongation, failure in the weld and tensile strengths less than that of the base material. Metallurgical explanation of the above results may be seen in the photomicrographs of this test condition in Figs. 4 and 5 and Table 4. Combined carbon in the weld is less than that necessary to saturate the ferrite. There are no visible carbides in either the as-welded or annealed structures. There are, however, a considerable number of oxide particles as well as nitride needles and, in the as-welded structure, an appreciable amount of another constituent (see darkened area in 4510—AIR, Fig. 5) which is likely an additional form of nitride precipitate. The existence of a rather thoroughly oxidized condition along with a sizable amount of nitride precipitate readily accounts for the somewhat inferior properties of ductility and strength.

Test results on weldments made with E6015 rod in air are likewise representative. Tensile test values were somewhat below expectation due to defects in the weld deposit. The weld bead is smooth, only slightly convex, with normal columnar grain structure, and is relatively free from voids and inclusions except as noted above. Bend and tensile test results indicate adequate ductility. Table 4 indicates a normal annealed structure with nearly complete carbon recovery and no nitride precipitate of any type. The volume of constituents other than ferrite appears somewhat greater in 6015—AIR, Fig. 5, than in the structure examined in the annealed condition, although in neither case are these nitride needles. This would lead one to the conclusion that the apparent difference in constituents other than ferrite in the as-welded structure is due to the presence of a form of nitride precipitate (much less detrimental to physical properties than nitride needles) in addition to carbides. It appears possible to redissolve these nitrides by annealing. This precipitation of nitrides in the cast condition followed by their resolution upon annealing is readily explainable. When the dendrites form from the melt, the first material solidified is that of highest melting point, i.e., lowest carbon (and probably oxide and nitride) content. During the last stages of solidification, the material in the interstices is high in carbon, oxygen and nitrogen. Under these conditions, nitride precipitates can readily appear. Subsequent annealing allows diffusion of the carbon, oxygen and nitrogen to a more uniform concentration which is apparently below that which will permit the precipitation of nitrides on cooling. In spite of the shielding provided by the electrode coating, there is still appreciable nitrogen absorption from the surrounding atmosphere. This point will be considered further in subsequent discussion.

The effect of nitrogen atmosphere (without oxygen) on the structure and properties of the weld are worthy of note. Considering first the bare rod weld, we see from Table 4 that in the annealed condition there are some carbides (less than in the rod itself) and no visible nitrides, while the microstructures of this weld condition shown in Figs. 4 and 5 indicate a precipitate of some type which appears to be far greater in volume than could be provided by less than 0.10% carbon. Also, there is absolutely no evidence, either in the as-welded or annealed condition, of the presence of nitride needles. Thus, a necessary condition for the formation of these needles must be the presence of appreciable amounts of oxygen. It is possible that the oxygen serves as part of an intermediate compound in the formation of this comparatively massive form of nitride precipitation as well as perhaps decreasing the solubility of nitrogen in the ferrite. The tensile and bend test results, although somewhat inconclusive, indicate a very considerable improvement in physical properties as compared to the bare rod weld in air. This may be attributed to a combination of absence of oxides and of needlelike nitrides in the weld structure.

Examination of the Tukon hardness results for the two bare rod welds, made in air and nitrogen atmospheres, reveals a very considerable increase in hardness in the latter case. In view of these and the other Tukon results, it is possible to conclude that the hardness increase is not attributable entirely to the increase in carbon content, but must in great measure be due to the presence of nitrogen, either in dissolved or precipitated form.

The appreciable increase in Tukon hardness of the shielded rod weld in nitrogen as compared to air must carry a similar explanation. In spite of the protective layer of slag provided by the rod, considerable amounts of nitrogen must have been absorbed in the molten pool or in the solid metal while it was near its melting range. Comparison of microstructures under these two conditions tends to substantiate the greater nitride precipitation in the nitrogen atmosphere and shows a somewhat finer cast structure in this latter case. See Fig. 3 (2) and (4) and corresponding structures in Figs. 4 and 5. This result is not surprising, since the presence of the greater amount of precipitate (particularly if it formed at or near the melting temperature) would serve to nucleate ferrite or austenite formation at a greater number of points and hence produce a finer structure. Although physical test results from the nitrogen atmosphere specimens are almost wholly masked by the presence of a tremendous amount of worm holes, there appears to be little other detrimental effect. Observation of the welding operation itself failed to uncover any evidence of this and it was not until the slag layer was removed that this effect was apparent. See Fig. 2 (4). Although the current setting may have been somewhat low for this rod,* and there were isolated instances of worm holes with the same rod deposited in air, there was no reason to suspect such general and concentrated

* Additional tests run at higher current settings indicated approximately the same frequency of existence of worm holes.

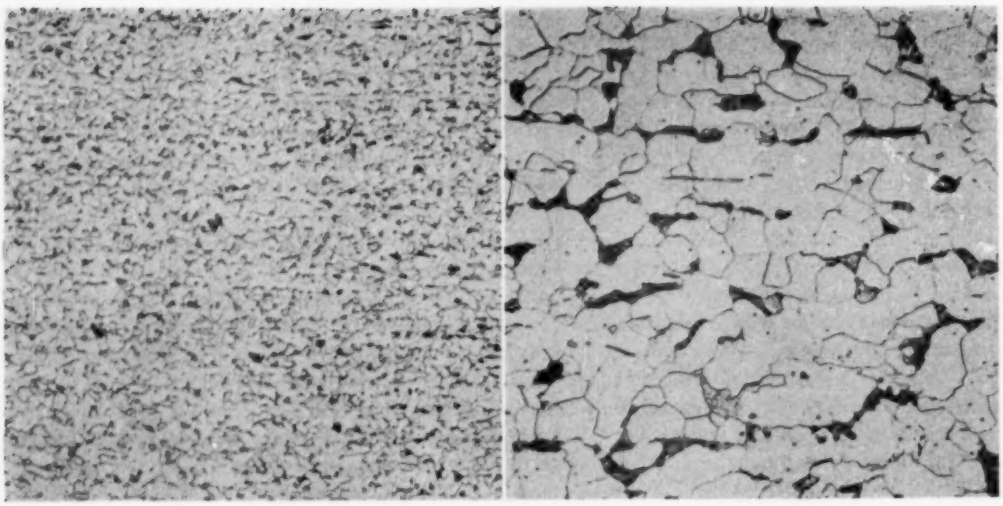

Fig. 6 Photomicrographs of untreated base material. Original magnifications 100 and 500 diam. Nital etch

distribution of this defect in the nitrogen atmosphere welds. Change of arc length and electrode position failed completely to eliminate this defect. Thus although there is a tendency toward the formation of worm holes in air, the effect is immeasurably greater in the nitrogen atmosphere. The authors are unable to account for this phenomenon.

Welding in a carbon dioxide atmosphere with a bare welding rod presented one problem not encountered in any of the other five test conditions, namely, exceedingly low arc stability. Whereas in air and nitrogen atmospheres the arc caused sufficient ionization of the diatomic gas or gases present to permit a steady arc, in the carbon dioxide there was insufficient ionized path to permit much more than a sputtering arc very similar to that obtained when an attempt is made to weld with a bare rod using an alternating current. It was possible to obtain only enough weld bead to permit micro- and macroexaminations. No tensile or bend-test samples were made under these conditions. Presence of the necessary ingredients in the coating of E6015 rod was evident in that welding with this rod in carbon dioxide atmosphere presented no difficulties of arc instability. It may be seen in Fig. 5 (4510-CO_2) that one of the reasons for the selection of the carbon dioxide atmosphere (oxidizing but without nitrogen) was justified. There is a very considerable oxide pickup in the weld, and neither in the as-welded nor the annealed condition is there any evidence of combined carbon. Tukon hardness values were slightly lower than in the rod welded in air, undoubtedly due to the hardening effect produced by the nitrogen pickup in the latter case. The use of the coated electrodes in a carbon dioxide atmosphere produced uniform welds with no obvious visual or macro defects. See Figs. 1 and 2. Figures 4 and 5 and Tables 3 and 4 show welds produced under these test conditions are somewhat lower in carbon apparent in both the as-welded and annealed conditions than those fabricated in natural atmosphere, of course devoid of nitrogen, and undoubtedly because of these facts are somewhat lower in hardness. The lower carbon content in this instance, like the presence of nitrides in the nitrogen atmosphere when using E6010 rod, indicates the incompleteness of protection from atmosphere provided by this rod. However, tensile and bend-test results indicate that the physical properties of the weldment have not suffered seriously by the application of this oxidizing atmosphere.

CONCLUSIONS

1. Arc stability was normal under all test conditions except when welding with bare rod in carbon dioxide atmosphere, where it became almost impossible to maintain an arc.

2. Quality of welds was normal as determined by visual and macro examination, except for the very irregular welds produced by bare rod in carbon dioxide atmosphere and the presence of a large amount of worm holes when welding with E6015 rod in nitrogen.

3. As a result of examination of microstructure and examination of Tukon hardnesses the following conclusions are drawn:

(*a*) Nitride needles are present only when welding with bare rod in air.

(*b*) Nitride formation other than needles occurs when welding in either air or nitrogen atmospheres with either E4510 or E6015 rod.

(*c*) These nitrides other than needles disappear upon annealing.

(*d*) These nitrides increase the hardness of the as-welded structure without seriously affecting the ductility.

(*e*) The presence of oxides and/or nitride needles produces a strong embrittling effect.

(*f*) The E6015 rod provides incomplete protection from the atmosphere.

4. The results of these tests indicate the possibility of evaluation of the effectiveness of carbon retention and protection from atmosphere afforded by various types of coated rods.

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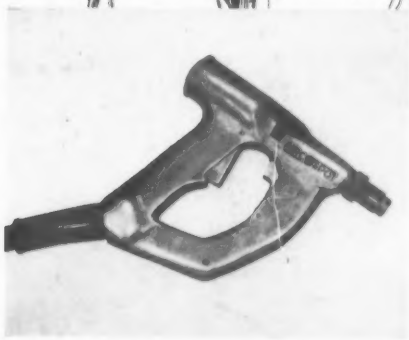

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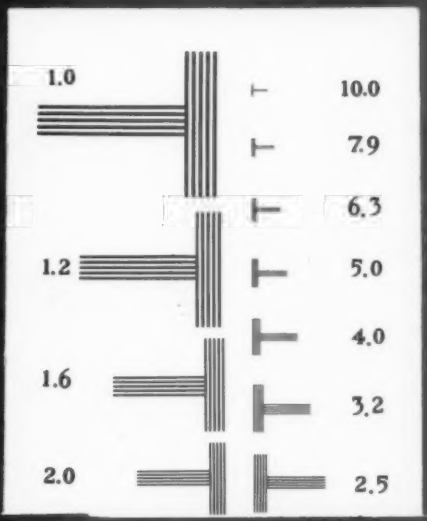
AN AIR REDUCTION PRODUCT

RESOLUTION CHART



100 MILLIMETERS

INSTRUCTIONS Resolution is expressed in terms of the lines per millimeter recorded by a particular film under specified conditions. Numerals in chart indicate the number of lines per millimeter in adjacent "T-shaped" groupings.

In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and $100/20 = 5$.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and $7.9 \times 5 = 39.5$ lines per millimeter recorded satisfactorily. $10.0 \times 5 = 50$ lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.

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